TEMPE AREA DRAINAGE MASTER STUDY

CONTRACT FCD 2012C021

LID APPLICATION REVIEW AND FLO-2D MODELING

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1.0 INTRODUCTION

1.1 Purposes and Goals

The purpose of this report for the Work Assignment No. 3 (WA3) of the Tempe Area Drainage Master Study and Plan (ADMS/P) is to conduct a comprehensive literature review of the green infrastructures (GI) and low impact development (LID) techniques, their applications, and hydrologic and hydraulic modeling methods to initiate and encourage the implementation of various LID controls and development of simulation tools in order to understand and quantify the individual and cumulative impact of LID controls on drainage and flooding in the arid Southwest. This report is also developed as a guidance document for creating local and regional hydrologic and hydraulic models with the capability to analyze conceptual scenarios of LID used for drainage and flood mitigation and water conservation.

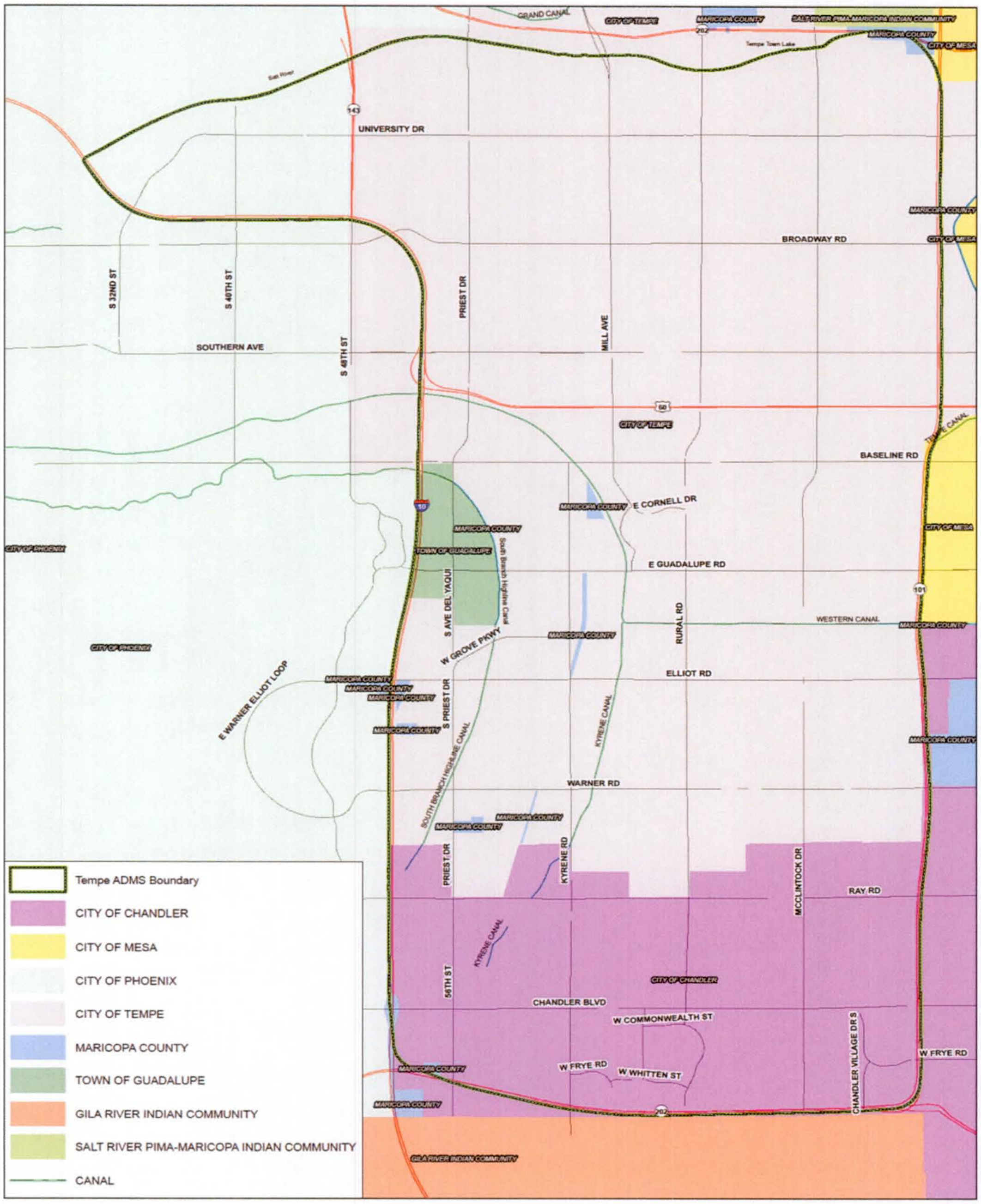
1.2 Background and Context

In the past few years, there have been multiple significant storm events causing extensive street drainage problems and flooding of several neighborhoods in the City of Tempe. Although Tempe is nearly built-out, with the advent of the light rail, ASU expansion plans, and the attraction of the Tempe Town Lake, major redevelopment of portions of the city is taking place. As a response to projected growth and regulatory requirements, the City of Tempe is considering implementation of various GI and LID techniques as part of the new General Plan 2040. The Arizona Department of Transportation (ADOT) also has several large drainage infrastructure projects related to improving the existing freeway network throughout this region. The freeway drainage network within Tempe includes several facilities that are undersized and will require major reinvestments in advance of projected freeway expansion projects. In response to these issues, the Flood Control District of Maricopa County (District) recognized a need to assess flooding in the area, and has initiated the Tempe ADMS to identify flood hazards and develop any needed flooding mitigation solutions for effectively addressing those flooding issues in a regional context and protecting the public and property owners while coordinating with community needs and future plans for the area.

The hydrologic and hydraulic modeling of the Tempe ADMS area by FLO-2D/SWMM models was documented in the *Tempe ADMS FLO-2D/SWMM Modeling Report* prepared by J2.

The Tempe ADMS study area is bounded by the Salt River on the north, Loop 101 on the east, SR 202 on the south, and I-10 on the west. The study area is approximately 47 square miles located primarily within the City of Tempe with portions in the adjacent Cities of Phoenix and Chandler as well as the Town of Guadalupe. Figure 1.1 shows the project area boundaries and location.

FLO-2D, integrated with EPA Storm Water Management Model (SWMM Version 5.0) model and developed by Riada, Inc., was selected to be applied for this project for the hydrologic and hydraulic modeling. The entire Tempe ADMS/P study area is divided into three (3) FLO-2D modeling areas: Model A, Model B, and Model C as shown in Figure 1.2. The Test Area model is within the Model A area. The FLO-2D modeling boundary delineations take into account of the factors such as off-site inflow hydrographs and FLO-2D grid hydrographs conversion from Model B to Model A and Model C. A grid size of 20 feet by 20 feet was applied for this project. The major features for the sub-models are summarized in Table 1.1.



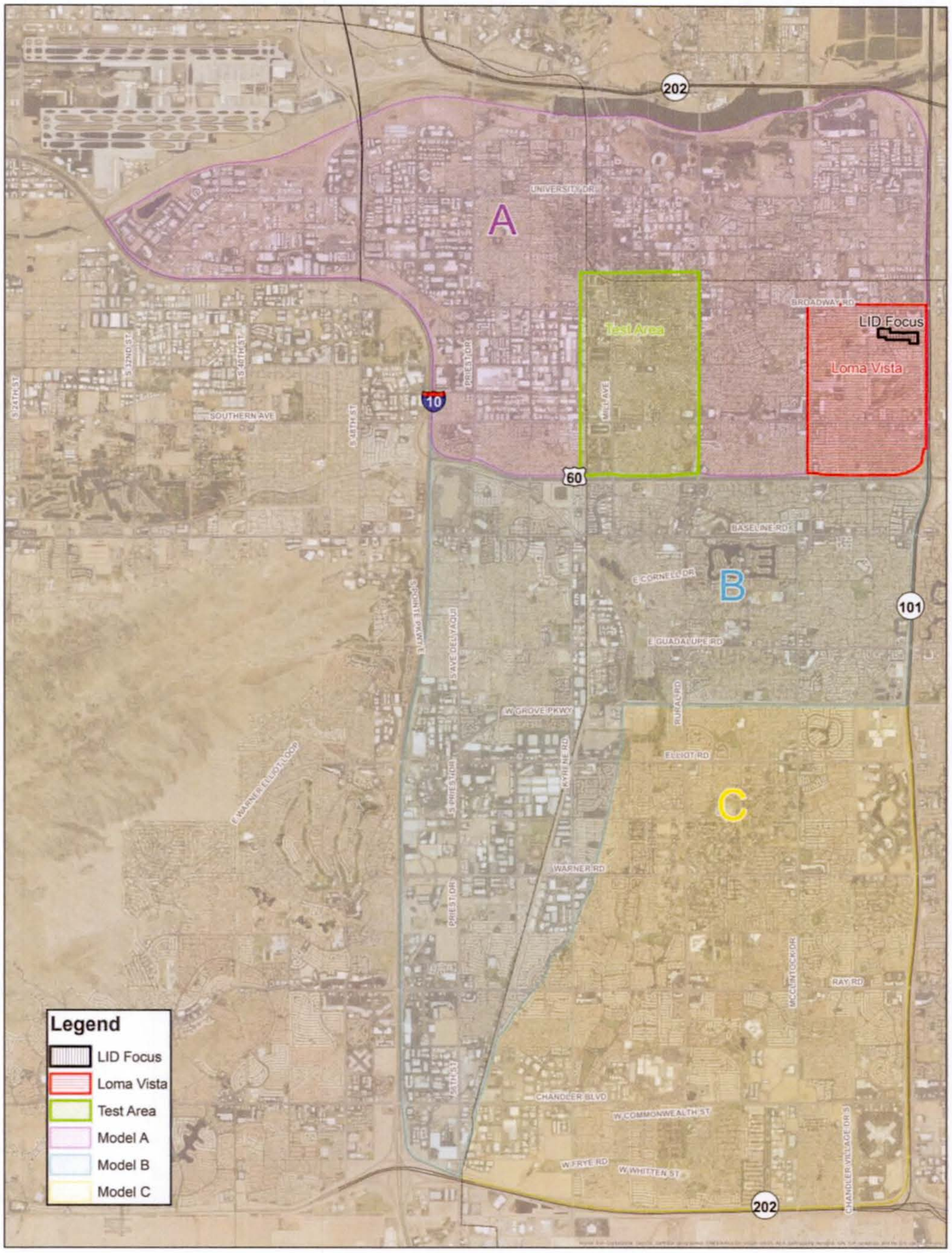
Tempe ADMS/P FCD 2012C021 - Work Assignment #2
Figure 1.1 Project Area Boundaries and Location Map

0 2,000 4,000 6,000 12,000 18,000 24,000 Feet

Table 1.1 FLO-2D Sub-Model Features				
Model	Model A	Model B	Model C	Total
Drainage Area ($mile^2$)	18	15	14	47
Total Number of Grids	1,238,647	1,027,788	1,010,360	3,276,795
Impervious Area (RTIMP, %)	59	56	48	55
Storm Drain Pipe Length (mile)	75	47	24	146
Number of Inlets	1,504	900	479	2,883
Number of Structures	17	2	22	41

The development of the input data files for all three models, model verification, and evaluation of modeling results were documented in detail in the *Tempe ADMS FLO-2D/SWMM Modeling Report*. Various maps for the development of input data files were created and modeling results were documented by the District post-processing tools as well as hydrographs and tables.

The FLO-2D program has a variety of parameters and processes that can be applied to model and quantify the impact of LID practices on the storm water volume and peak flows.



Tempe ADMS/P FCD 2012C021
Figure 1.2: FLO-2D Study Boundaries for Models A, B, C, and Test Area

0 2,000 4,000 6,000 12,000 18,000 24,000 Feet

1.3 Project Team

J2 Engineering and Environmental Design (J2) has been retained to perform these services as a part of the District On-Call Contract FCD 2012C021. J2 team for the WA3 includes Watershed Management Group (WMG) as a sub-consultant. The District is located at 2801 West Durango Street, Phoenix, AZ 85009, (602) 506-1501. The Project Manager for the District is Mr. Burke Lokey, P.E., PMP, CFM. J2's Project Manager for this project is Mr. Jeff Holzmeister, P.E.

J2 team is very appreciative to have the opportunity to represent the District in the performance of these services. This professional assignment presented many interesting and unique challenges requiring creative teamwork solutions. Mr. Burke Lokey, Mr. Richard Waskowsky, Mr. Doug Williams, Mr. Thomas Loomis, and Mr. Pedro Melo-Rodriguez of the District; and Mr. Gregg Kent of the City of Tempe provided critical technical support and decision-making guidance throughout the duration of the study. Their individual and group contributions played a key role in the successful completion of this assignment.

2.0 LOW IMPACT DEVELOPMENT (LID) CONCEPT AND PRACTICES

2.1 Overview of LID General Practices

LID is a sustainable approach to stormwater management that utilizes the landscape to absorb storm runoff and reduce offsite flows that can contribute to flooding and infrastructure costs. The basic principle is to model after nature: manage runoff at the source using distributed micro-scale controls. The goal of LID is to mimic and sustain predevelopment hydrologic conditions by using techniques that store, detain, retain, infiltrate, evaporate, and re-use stormwater runoff to support native and designed landscapes, groundwater recharge, and water quality improvement. They can be utilized to supplement, and sometimes reduce the need for, traditional methods for stormwater management. While conventional methods often channelize and pipe runoff away from development, LID methods utilize this water close to its source, to support vegetation and reduce runoff volume.

LID is adaptable to a wide range of land use types and project scales. Breaking down developed areas into their constituent components – residential areas, commercial properties, and public realm; buildings, paved areas and landscape – presents a way to organize potential controls to implement LID.

Increased stormwater runoff is directly related to the amount of impervious surfaces in a given area and to how land is developed and improved. Improvements in managing stormwater can have multiple benefits for cities, their residents, and businesses. LID actions can be taken by governments, organizations, and private interests. The benefits of LID have been published for many national and local examples, and are supported by the Environmental Protection Agency (EPA) in its Municipal Separate Storm Sewer System (MS4) requirements.

The benefits of LID applications can be summarized as follows:

- Flood control: Detain stormwater close to its sources and reduce runoff volume and peak flows to any downstream stormdrain, retention basin, or stormwater system;
- Maintenance: Collects sediments to reduce drainage facility maintenance costs;
- Environmental: Reduce pollutants in stormwater runoff and improve water quality;
- Water supply: Utilize stormwater to support native and non-native vegetation and landscape improvements and reduce irrigation water demand;
- Landscape: Combine with traditional landscape to reduce costs;
- Traffic calming: Modify streets to combine with traffic calming measures.

A literature research and review of potential LID applications has been conducted in order to identify various LID controls for applicability in Tempe and Maricopa County. While LID has been used in limited cases in Tempe, the practice in metropolitan Phoenix and Arizona is gaining ground as one of the viable controls available to reduce stormwater runoff, provide water quality improvement along with other environmental and quality of life benefits. Other urbanized areas in the United States have been more vigorously implementing LID predominantly due to water quality issues first and volume secondarily. The collected major references are generally classified into five categories: a) Publications for LID general practices; b) Publications of LID applications in Southwest Regions; c) Tempe LID practices; d) LID application Case Studies; and e) Modeling methods of LID practices including hydrologic and hydraulic modeling, and benefit/cost estimations. The major references are included in Appendix A and are discussed in the following sub-sections.

The major publications for the first category are included in Appendix A1and are summarized as follows:

EPA, in December 2007, published a report titled *Reducing Stormwater Costs through Low Impact Development (LID) - Strategies and Practices*. While this study focuses on the cost reductions and cost savings that are achievable through the use of LID practices, it also shows that communities can experience many amenities and associated economic benefits that go beyond cost savings. These include enhanced property values, improved habitat, aesthetic amenities, and improved quality of life.

In December 2008, EPA released a handbook titled *Managing Wet Weather with Green Infrastructure Municipal Handbook – Green Streets*. The use of green streets offers the capability of transforming a significant stormwater and pollutant source into an innovative treatment system. Green streets optimize the performance of public space easing maintenance concerns and allowing municipalities to coordinate the progression and implementation of stormwater control efforts. In addition, green streets optimize the performance of both the transportation and water infrastructure. Effectively incorporating green techniques into the transportation network provides significant opportunity to decrease infrastructure demands and pollutant transport.

Baker, in June 2011, drafted a Municipal Handbook for EPA as well – *Low Impact Development and Green Infrastructure: Role in Flood Risk Management*. This handbook is trying to demonstrate the functions and benefits of LID applications on flood mitigation.

In January 2015, EPA published *Green Infrastructure Opportunities that Arise during Municipal Operations* which provides approaches local government officials and municipal program managers in small to midsize communities can use to incorporate green infrastructure components into work they are doing in public spaces. This guide demonstrates ways in which projects can be modified relatively easily and at a low cost recognizing that municipal resources can be limited.

In April 2015, EPA published *A Guide for Local Governments – Community Based Public-Private Partnerships (CBP3s) and Alternative Market-Based Tools for Integrated Green Stormwater Infrastructure*. This guide provides communities with an opportunity to review the capacity and potential to develop a P3 program to help "close the gap" between current resources and the funding that will be required to meet stormwater regulatory commitments and community stormwater management needs.

Earlier, in October 2000, EPA published a literature review on LID to determine the availability and reliability of data to assess the effectiveness of LID practices for controlling stormwater runoff volume and reducing pollutant loadings to receiving waters. Background information concerning the uses, ownership and associated costs for LID measures was also compiled. The conclusions are still valid.

In general LID measures are more cost effective and lower in maintenance than conventional, structural stormwater controls. Not all sites are suitable for LID though. Considerations such as soil permeability, depth of water table and slope must be considered, in addition to other factors. Further, the use of LID may not completely replace the need for conventional stormwater controls.

Maintenance issues can be more complicated than for conventional stormwater controls because many LID measures rely on multiple facets including but not limited to permeability, biometrics, sub-grade media, and available area. This can be further complicated if these measures reside on private property. In most instances, homeowners agree to only the first year of maintenance. Homeowner associations could be a mechanism for providing long-term maintenance to these areas. Generally, bio retention facilities require replacement of dead or diseased vegetation, remulching as needed, and replacement of soils after 5–10 years. Bio swales require periodic mowing and removal of sediments. Maintenance of permeable/pervious pavements requires annual high-powered vacuuming of the area to remove sediments.

Several studies have been conducted to analyze the effectiveness of various LID controls based on hydrology and pollutant removal capabilities. **Bio retention areas, bio swales, pervious pavements and green roof were the most common practices studied**. These techniques reduce the amount of Effective Impervious Area (EIA) in a watershed. EIA is the directly connected impervious area to the storm drain system and contributes to increased watershed volumes and runoff rates. There are documented case studies that conclusively link urbanization and increased watershed imperviousness to hydrologic impacts on streams. Existing reports and case studies provide strong evidence that urbanization negatively affects streams and results in water quality problems such as loss of habitat, increased temperatures, sedimentation and loss of fish populations (EPA, 1997).

In general bio retention areas were found to be effective in reducing runoff volume and in treating the first flush (first ½ inch) of stormwater. Results from three different studies indicate that removal efficiencies were quite good for both metals and nutrients. Removal rates for metals were more consistent than for nutrients. Removal rates for metals ranged from 70–97% for lead, 43–97% for copper and 64–98% for zinc. Nutrient removal was more variable and ranged from 0–87% for phosphorus, 37–80% for total nitrogen, 0–92% for ammonium, and 0–26% for nitrate. Effluent volumes were lower than influent volumes. These studies were conducted by means of simulated rainfall events. Analysis of actual long-term rainfall events would produce more reliable data.

The effectiveness of bio swales was also quite good for both pollutant removal and runoff volume reduction. A study of three different sites in the United States reveals similar results despite the differences in location. In general, performance of swales is dependent on not only channel length, but also longitudinal slope and the use of check dams to slow flows and allow for greater infiltration. Further, the removal of metals was found to be directly related to the removal rate of total suspended solids, and the removal rate of metals was greater than removal of nutrients.

Reduction of impervious surfaces can greatly reduce the volume of runoff generated by rainfall. Several methods can be employed to reduce total impervious surface area. Pervious pavements and vegetated rooftops are two methods to accomplish this goal. Vegetated rooftops have been used extensively in Germany for more than 25 years and results show up to 50% reduction in annual runoff in temperate climates. Many opportunities exist to retrofit these systems into older highly urbanized areas of the United States. The Philadelphia project case study provides an example of this practice.

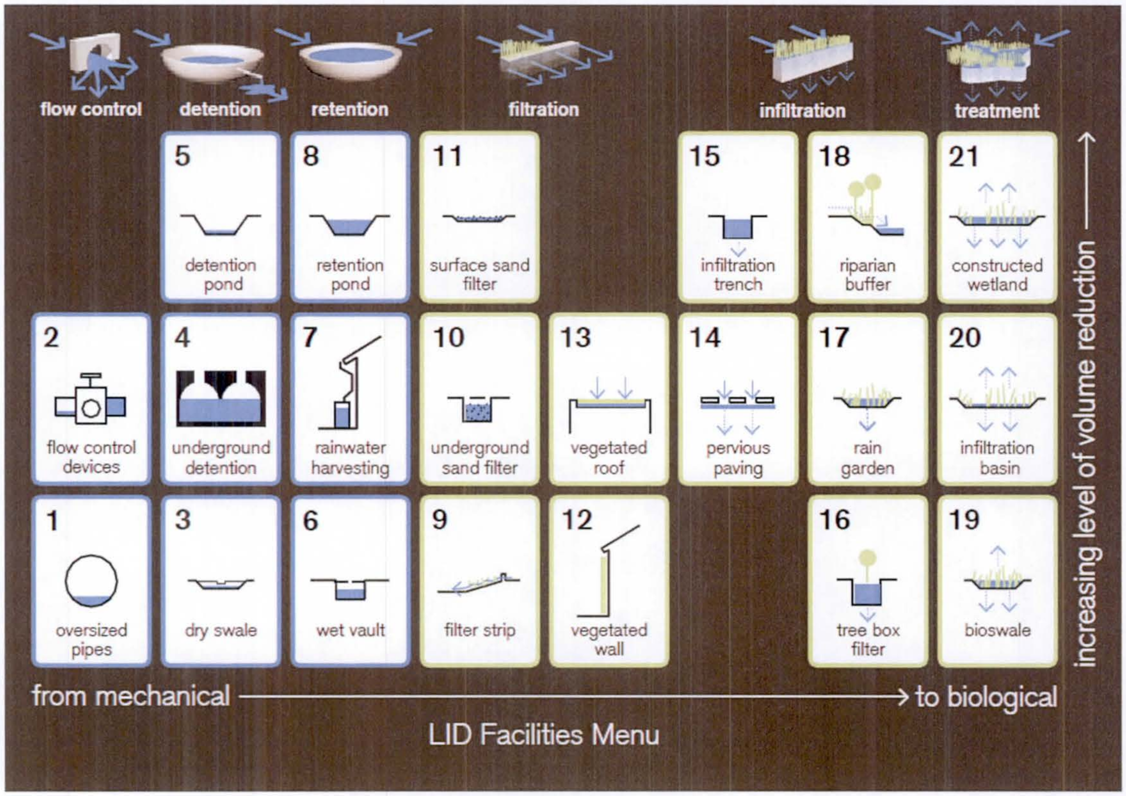
Pervious pavements can also reduce impervious surfaces. However, they are more expensive to construct than traditional asphalt pavements. Costs of these systems may be offset by the reduction of traditional curb and gutter systems to convey stormwater. Benefits of these alternate pavement types include better infiltration, ground water recharge, reduction in runoff volume and treatment of stormwater for pollutants. The study conducted in Tampa, Florida outlines these benefits as well as the opportunity to retrofit pervious pavements into existing parking lots with little or no loss of parking spaces. Less than 20% of rainfall was converted to runoff when using pervious pavements. Study results from the University of Washington, compare several different treatments of varying permeability. The study shows that the higher the amount of pervious area of the treatment, the greater the reduction of runoff volume and pollutant loadings.

Most of the available data are from Prince George's County, Maryland, which pioneered the use of LID. The data available for bio retention analysis were from single simulated storm events in actual bio retention facilities or from laboratory constructed and tested bio retention systems. The data for bio swales were for only a few storm events, collected over a short period of time. The only available data for a long-term study came from the Aquarium parking lot in Tampa, Florida and the Washington pervious pavement project. More long-term analysis is required to more accurately assess the effectiveness of LID and to determine long term trends.

In addition to EPA publications, many manuals and studies related to LID have been published, such as *LID Manual for Michigan* released in 2008; University of Arkansas published a LID manual in 2010 titled *Low Impact Development: a design manual for urban areas*; the BMP Database was also developed by Geosyntec Consultants, Inc. in May 2012 to document the analysis of volume reduction in bio retention BMPs. Oregon State has published specific LID site design practices. Green Nylen, Nell, and Michael Kiparsky, 2015 published a paper titled *Accelerating Cost-Effective Green Stormwater Infrastructure: Learning from Local Implementation*, Center for Law, Energy & the Environment, U.C. Berkeley School of Law.

The following LID controls Menu was developed by University of Arkansas and summarizes the general ideas and relationships of traditional flood control structures and LID facilities. This Menu organizes controls based on increasing level of treatment service (storm water quality) as well as increasing level of volume reduction (storm water quantity). Therefore, number one (1), oversized pipes offer the least amount of treatment services while number twenty-one (21), constructed wetland offers the most. Most municipalities require drainage infrastructure to manage the 100-year storm events. Though one facility alone will not likely satisfy performance requirements, facilities with varying levels of service in a LID system will provide superior levels of storm water treatment and flood volume reduction.

The District has compiled a list of LID studies and publications in a spreadsheet format. A list of website links to LID studies and publications was also prepared for easy usage. All of the references are listed in Appendix A1.



2.2 Survey of Regional and Local LID Practices

2.2.1Regional LID Practices

As discussed previously, other urbanized areas in the United States, especially in the southwest areas, have been more vigorously implementing LID practices predominantly due to water quality issues first and volume secondarily.

Several counties, cities, and state government agencies in California State have developed manuals and handbooks to guide and encourage the applications of LID techniques including Los Angeles County and City, San Diego County and City, San Mateo County, Riverside County, City of Riverbank, etc. These manuals and handbooks are included in Appendix A2.

Another state in the southwest region, Nevada, also has applied LID practices. For example, a LID Handbook for the Truckee Meadows Regional Stormwater Quality Management Program was developed in August 2007, and a Final Report for Xeriscape Conversion Study was prepared by Southern Nevada Water Authority in 2005. These publications are included in Appendix A2.

In metropolitan Phoenix and Arizona, Application of LID techniques is gaining ground as one of the viable controls available to reduce stormwater runoff, provide water quality improvement along with other environmental and quality of life benefits. City of Tucson published Water Harvesting Guidance Manual and Stormwater Quality Ordinance in 2005 as well as Watercourse Maintenance Guidelines in 2007. Specifically, Pima County and City of Tucson developed LID and GI Guidance Manual in 2015.

Watershed Management Group (WMG) develops community-based solutions to ensure the long-term prosperity of people and health of the environment and provides people with the knowledge, skills, and resources for sustainable livelihoods. They have developed many LID newsletters, training sessions, and design standards. These documents are included in Appendix A2. WMG is a sub-consultant to this study and provided the descriptions of the general concepts of basic LID controls in Section 3.2.

City of Scottsdale has developed a LID Techniques Tool Box and applied some of the techniques in Granite Reef Watershed study as implementation demonstrations.

City of Mesa has developed and handbook titled LID Toolkit in 2015. Some of the photos, descriptions, and data have been used in this report. However, the water budget calculation methods documented in this handbook cannot be used for spatially varied hydrologic and hydraulic modeling for the LID applications. All of the references mentioned in the regional LID section are included in Appendix A2.

2.2.2 Tempe LID Practices

LID Applicability in City of Tempe

Since the start of the Tempe ADMS project, J2 team has developed a white paper and several memos related to LID applications and modeling in Tempe under the directions of the District project manager. The white paper was prepared by Black & Veatch in March 2014 and the paper title is *Evaluation of Sustainable Stormwater Management Practices*. The first memo was developed in August 2014 to document the potential LID applications, City of Tempe requirements, and the proposed FLO-2D modeling procedures for selected LID practices. Nine (9) possible LID practices were identified in this memo.

The second memo was prepared in July 2015 to update the first memo including more detailed land use applications and refined FLO-2D modeling approaches. The proposed potential LID practices were further evaluated and the memo outlines the reasons and supporting documentation for the reduction from nine (9) to six (6) basic LID controls.

The third memo was prepared in September 2015 to document the five (5) selected LID controls, identified LID accessories (add-ons), and the proposed FLO-2D modeling procedures for selected LID controls and participation ratios. The Test Area FLO-2D model was utilized for the modeling of LID practices and combinations.

The fourth memo was developed in October 2015 to document the five (5) selected LID controls, identified accessories, and the proposed FLO-2D modeling procedures for selected LID controls and participation ratios. A new FLO-2D model with 4 ft x 4ft grids was developed for a Focus Area in order to simulate the infiltration processes and LID accessories. The study boundaries for FLO-2D models Loma Vista and Focus Area are shown in Figure 2.1. FLO-2D modeling techniques for each of the five selected LID controls were developed and tested. FLO-2D modeling procedures for regional LID application scenarios were also proposed.

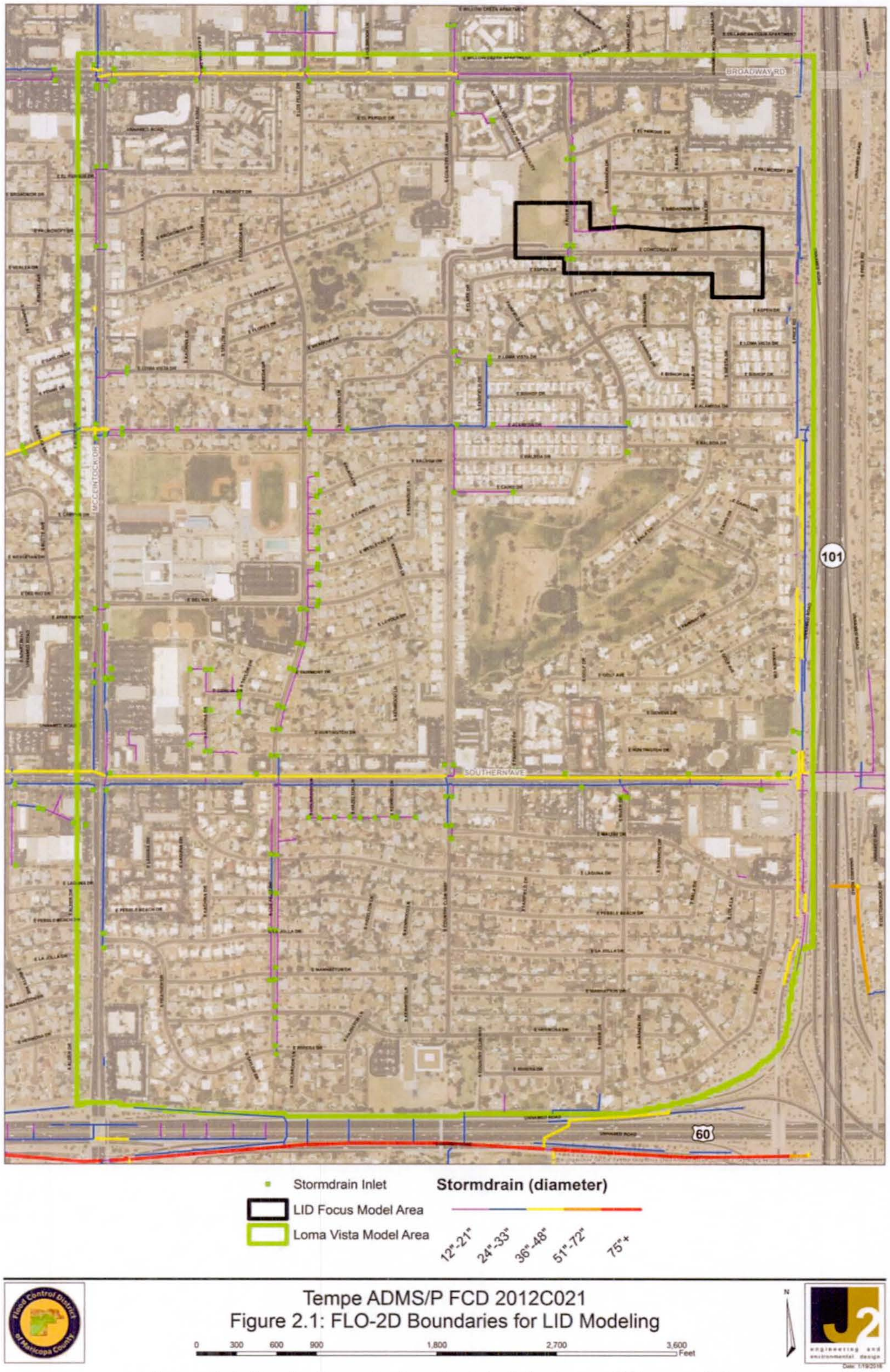


Figure 2.1 Study Boundaries for Models Loma Vista and Focus Area

The four memos and the white paper are included in Appendix A2. Table 2.1 summarizes the five selected basic LID controls (tools) for potential applications in Tempe for various land uses. Where "High" means highly applicable and "N/A" means not applicable for this LID control to the land use type.

Table 2.1 LID Applicability in City of Tempe

LID Basic Controls\ Land Uses	Single Family Residential	Multi-Family Residential	Commercial	Industrial	School	Community Center/Park	Street
Bio Retention	High	High	High	High	High	High	Medium
Bio Swale	Medium	High	High	High	High	High	High
Pervious Pavement	Medium	High	High	High	High	High	High
Rainwater Harvesting	High	High	High	High	High	High	Medium
Green Roof	Low	Low	Medium	Medium	Low	Medium	N/A

LID Evaluation by City of Tempe

The City of Tempe developed a document titled *Low Impact Development Evaluation* in June 2013. This document started LID evaluation with a review of existing stormwater practices related to planning, construction, and redevelopment including review of Tempe Municipal Ordinance and practice examples. Then, LID practices, their applicability, and regulatory hurdles were discussed. Three mechanisms were identified to promote and encourage LID applications including leading/organizational ownership, stormwater quantity/quality alignment, and public outreach.

The City of Tempe has identified various types of LID practices that should be further encouraged and a series of LID practices that cannot be embraced by the City:

A. *LID Practices Tempe Will Encourage/Support*
   - Alternative retention systems
   - Depressed landscaping
   - Use of drought tolerant plants (in tandem with street or harvesting projects)
   - Stormwater pretreatment systems
   - Pervious parking
   - Pervious concrete
   - Pervious surface treatments
   - Xeriscape conversion
   - Water harvesting (consistent with retention and vector control)
   - Various uses for permeable/pervious pavers
   - Impervious area reduction
   - Incentive program
     - Public recognition (under evaluation)
     - "C" value reduction, a coefficient for relating the runoff to rainfall in the Rational Method for estimating stormwater runoff
     - Reduction in number of drywells as a result of "C" value modifications

- LID recommendations for redevelopment projects that don't meet the on-site retention triggers (i.e. 25% area of impact and/or value trigger)
- Continued use of LID practices in CIP projects
- LID streetscape projects

B. *LID Practices Tempe Will Not Endorse*

- Practices contrary to conservation efforts
- Practices that could negatively impact operation of the City-owned and operated stormwater system
- Practices that increase on-site retention requirements
- Practices that could impact neighboring property
- Practices that require future increased maintenance and/or monitoring by the City (non-CIP)

As a result of this evaluation, Tempe has made a commitment to continue to promote LID by example by incorporating acceptable practices in CIP projects and subscribing to the LID objectives outlined in the Tempe General Plan 2040. Additionally, Tempe hopes to incorporate LID concepts to address future flooding mitigation efforts.

<u>Potential LID Implementation Strategies</u>

As mentioned previously, Black & Veatch, a sub-consultant to J2 for the Tempe ADMS/P project, prepared a white paper titled *Evaluation of Sustainable Stormwater Management Practices* in order to evaluate the City's existing SWMP and associated ordinances with respect to their MS4 permit requirements. The evaluation included a review of the various programs within the City's existing SWMP, including its Stormwater Retention Ordinance.

Tempe has, for the most part, been completely "built-out" with no new open development parcels remaining in the City. With this in mind the ***Potential LID Implementation Strategies*** will need to be focused on infill redevelopment and the retrofit of existing lands, buildings, developments and roadways. To this end potential implementation strategies for Tempe will look at projects and policies that can be implemented through codes for redevelopments, defined Capital Improvement Projects (CIP) for buildings, sites and roadways owned and operated by the City, partnerships with schools and private businesses and incentive programs for private homes and businesses.

The four general strategies by which projects may be implemented are:

1. Code requirement for new development, renovations and infill projects;
2. Capital Improvement Projects (CIP);
3. Public/Private Partnerships;
4. Incentive Programs.

Code requirement for new development, renovations and infill projects

When new development, renovation or infill development occurs, the opportunity to implement LID practices is available if City codes are in place to require the development to enact strategies to reduce and slow stormwater runoff from the project site. While there are different ways to "codify" the stormwater reduction requirements, one which exists is the stormwater retention requirements (retain on site a 100 year 2 hour storm). The City also has Alternative Retention Criteria Areas (ARCA) which are required to retain on site a 2 year 2 hour storm. This code has been very helpful in reducing flooding in the newer development areas of the City. The "pre retention" code areas would be the best opportunity to implement LID as a part of the retention requirement to reduce runoff volume.

Quantification of LID volumes and acceptance by agencies has been a hurdle to overcome in the past. By actively defining the process and quantifications that make it equal to or less burdensome to navigate a project through the development permitting process would enhance the implementation of LID measures. A tool that may help with implementation of LID would be a LID stormwater manual for the City of Tempe. The manual could show example scenarios that may be used on new, renovation and infill projects. The manual would also need the "hard data" quantification formulas for each scenario. In addition to the hard data, there would be examples of how some LID stormwater methods may also overlap with City planning codes for landscape, open space parking and aesthetics. Preliminary evaluation results show that the basic LID controls have code implementation opportunity during new development, renovation, and infill development.

Capital Improvement Projects (CIP)

Throughout the City, CIP projects are continuous occurring providing maintenance rehabilitation and new works. There exists an opportunity to incorporate LID into several of these existing projects, such as streets, parks and buildings, along with future projects. In addition defining and creating new LID CIP specific or overlap projects can be incorporated into the CIP process.

Public/Private Partnerships

Examples of public/private partnerships may include private businesses, schools, churches, the university, utility companies and the railroad. These all have lands that are either disused "forgotten lands" that are serving no particular purpose and are ongoing maintenance for the owner. In addition many of these property owners have open lands that are "non time critical lands" such as open landscape areas, park/school/church open space, and practice fields. All of these lands are prime opportunities to create basins, "rain gardens" and "bio swales."

Incentive Programs

Incentive programs for local runoff reduction may be a good opportunity to not only reduce runoff but engage the public to actively participate in a LID program. The benefits could be increased public support, reduced runoff, reduced potable water consumption for landscapes, increased bio mass, shade, heat island reduction, reduction of materials going to landfills, aesthetic enhancements, and neighborhood stabilization/enhancement.

The City currently has an incentive program for single-family residents to convert grass lawns to xeriscape on a square footage basis. This program would be a prime opportunity to combine with an LID incentive program.

2.2.3 LID Case Studies

Many LID application projects have been implemented in recent years. A few case studies are reviewed here. Spokane Urban Greenway Ecosystems for Lincoln Street, Washington State, LID practices including bio-infiltration system were constructed to assist traditional inflow reduction technology, such as detention, vortex separators, and treatment plant upgrades.

Three LID case studies by Massachusetts Department of Conservation and Recreation in the Ipswich River Watershed included LID controls of porous pavements, bio retention, and bio swales.

1D/2D Modeling of Decentralized Stormwater Control Measures for Flood Mitigation in Austin, Texas was conducted by Geosyntec Consultant for a drainage area of 368 acres. SWMM program was applied to model the hydrologic and hydraulic impact of LID controls on flood.

Pima County Flood Control District and WMG performed the study for the Airport Wash by solving flooding challenges with green stormwater infrastructure. FLO-2D program was used for the modeling of LID hydrology and hydraulics by adjusting TOL parameters spatially.

In City of Tempe, LID measures were incorporated into CIPs, such as Maple Ash/Mitchell Park East Traffic Calming Improvements and College Avenue Traffic Calming Projects. The District has collected a list of LID application projects in the local areas and documented in a spreadsheet. These case study reports and the District spreadsheet are included in Appendix A2 for detailed information.

2.3 Review of LID Simulation Methods

Hydrologic and Hydraulic Modeling

Modeling methods of LID applications include hydrologic and hydraulic modeling, and benefit estimations. Quantification of LID practices on flood reductions has been a hurdle to overcome in the past. Therefore, one of the objectives for the Tempe ADMS/P project WA3 is to identify how the ADMS/P hydrologic and hydraulic modeling effort could be utilized to help Tempe in the evaluation of LID controls.

Early in July 1999, Prince George's County, Maryland developed some methods to simulate the hydrologic impact of LID practices using NRCS curve number program, such as reducing Runoff Curve Number, increasing Time of Concentration, adding Retention basin, and Detention basin. This program is a lumped program and cannot model spatially varied LID practices in detail.

Lately, Geosyntec Consultants (2015) applied PCSWMM for 1D/2D Modeling of Decentralized Stormwater Control Measures for Flood Mitigation in Austin, Texas. EPA SWMM can explicitly model five different generic types of LID controls as well. However, it is difficult to apply this program to a parcel level detailed-modeling. The general methodologies for these two programs are summarized in Appendix A3.

In 2009, Guo published a research paper titled *Preservation of Watershed Regime for Low Impact Development* and presented a simplified method by which a LID design can be quantitatively evaluated for a full spectrum control of runoff population. USGS (2010) also published a report (Circular 1361) titled *Effects of Low-Impact-Development (LID) Practices on Streamflow, Runoff Quantity, and Runoff Quality in the Ipswich River Basin, Massachusetts: A Summary of Field and Modeling Studies* and documented the method of modeling the impact of LID practices on flood in watershed scale.

In City of San Diego *Low Impact Development Design Manual,* several methods were recommended for the hydrologic and hydraulic modeling of LID practices including HSPF (Hydrological Simulation Program in Fortran) model Functional Tables.

Central Vermont Regional Planning Commission developed a model which utilized impervious surface data, GIS build-out analysis data and average rainfall amounts to demonstrate the increases in stormwater run-off if development continued to occur without LID strategies in place. An alternate model was created to illustrate the amount of stormwater runoff if development incorporated LID techniques.

EPA, in 2014, developed a National Stormwater Calculator tool which is a simple to use tool for computing small site hydrology for any location within the US. It estimates the amount of stormwater runoff generated from a site under different development and control scenarios over a long term period of historical rainfall. The analysis takes into account local soil conditions, slope, land cover and meteorology. Different types of LID practices can be employed to help capture and retain rainfall on-site. Future climate change scenarios taken from internationally recognized climate change projections can also be considered. These reports and manuals are included in Appendix A3.

Benefit Estimation Programs

Understanding the economics is as important as understanding the planning and technical mechanics of LID stormwater-water infrastructure design solutions. The Pima County Regional Flood Control District & Pima Association of Governments with the Cooperation of the City of Tucson has developed a tool called AutoCASE™ that was applied for the evaluation of LID benefits in Pima County Environment. This cost-benefit report, tailored with data specific to the arid southwest, is a tool to evaluate the spending of public funds for LID solutions. The report and presentation slides are included in Appendix A3.

General Help Tools

In 2012, Envision™ was developed in joint collaboration between the Zofnass Program for Sustainable Infrastructure at the Harvard University Graduate School of Design and the Institute for Sustainable Infrastructure. Envision™ rating system is designed to be used not only as a project assessment tool but as a guideline for sustainable infrastructure design including LID practices and integrated education and resource library. This assessment recognizes the need to stretch the traditional design boundaries in which infrastructure projects are judged not only by how they are delivered, but also by how long they last, accounting for durability, flexibility and utility of the constructed works. This new sustainable infrastructure rating system is a cutting-edge development for the world's infrastructure design and built environment.

Desert Water Harvesting Institute also developed a tool which is called Water Harvesting Assessment Toolbox. The goal of the Water Harvesting Assessment Toolbox is to help communities in the Southwest US identify water resource challenges, understand the role water harvesting can play in meeting these challenges as well as providing multiple additional benefits, and implement locally-appropriate water harvesting efforts including LID practices. The Toolbox is intended for use by a wide range of water resource decision-makers and community members. Use of the Toolbox is conducted with the assistance of a local facilitator who oversees the assessment process and utilization of the five tools provided with the

Toolbox. The manuals and programs/spreadsheets for these tools are included in Appendix A3.

2.4 Introduction to FLO-2D Modeling of LID Practices

Recently, FLO-2D has been modified to model LID practices. Riada has revised the program to have spatially varied TOL values to model LID controls and released a handout – *FLO-2D Low Impact Development (LID) Modeling* which is included in Appendix A4. Spatially variable TOL values would be assigned on a grid element basis to represent the composite LID techniques on a given grid element. Depending on the size of the LID feature, multiple grid elements may represent an individual lot or a LID control. Different grid elements may represent different LID techniques. The potential volume of on-site retention storage can be assessed by multiplying the LID control surface area by the retained flow depth (TOL value). This would provide flood hazard mitigation on a lot by lot basis.

This approach has been utilized by Pima Flood Control in Airport Wash Area (Tucson, AZ). The report and emails related to this project are included in Appendix A4. The FLO-2D model developers of this project, Janice Hughes and Evan Canfield have provided insight on their modeling efforts in Pima County. In hindsight, they would have utilized different methodologies (IA adjustment, etc.) to model the impact of LID, but Pima County does not utilize the Green Ampt methodology in their hydrologic analysis. Therefore, they chose to utilize the TOL adjustment for their model. Since the surface detention parameter (TOL) is artificially ponded water and is the minimum value of the flow depth for flood routing (mathematic computations), maintaining the lower TOL value will theoretically produce more accurate results.

FLO-2D, integrated with EPA SWMM Version 5.0 model, routes surface runoff over unconfined flow surfaces/channels using the dynamic wave approximation to the momentum equation while maintaining volume conservation. Finite difference algorithms are utilized to solve the partial differential equations. EPA SWMM is integrated with FLO-2D to simulate storm drain systems. More detailed information about the capabilities and applications of FLO-2D can be found in the references. The FLO-2D software, Pro Version, Model-Build No. 15.02.10, release date of March 19, 2015, was applied for the modeling of the LID practices.

2.4.1 Review of Available Model Parameters

The FLO-2D program has a variety of parameters and processes that can be applied to model and quantify the storm water volume and peak flow as documented in previous J2 memos. The following is a preliminary list of the capabilities and parameters of FLO-2D that may be utilized for LID modeling.

A – Grid elevation adjustment: Lowering the grid elevations (on-lot – within the LID area or off-site – near the LID area) can increase the retention/detention storage to mimic the volume reduction of a specific LID control;

B – Initial loss abstraction IA adjustment: Increasing the values of IA for the grids within the LID area can be used to model the rainfall depth/volume reduction of a specific LID control;

C – TOL value adjustment: Increasing the values of TOL for the grids within the LID area can be used to model the rainfall depth/volume reduction of a specific LID control;

D – Infiltration rate adjustment: Increasing the values of infiltration rate for the grids within the LID area can be used to mimic the rainfall depth/volume reduction of a specific LID control;

E – Limiting soil depth adjustment: Increasing the values of limiting soil depth for the grids within the LID area can be used to model the rainfall depth/volume reduction of a specific LID control;

F – Spatially variable rainfall data: Reducing the values of rainfall depth for the grids within the LID area can be used to mimic the rainfall depth/volume reduction of a specific LID control;

G – Diversion by a structure: An artificial diversion by a structure can be used to model some LID controls that can transfer concentrated flows;

H – Boundary outflow grid: Additions of boundary outflow grids can be used to account for the losses of runoff volume from a specific LID control area;

I – Use of artificial WRF: Additions of WRF (Width Reduction Factor) around the grids within the LID area to block the flow movement can be used to store the rainfall depth/runoff volume of a specific LID control;

J – Use of artificial levee: Additions of levees around the grids near the LID area to control the flow directions and locations can be used to model the runoff into LID area of a specific LID control;

K – Use of artificial storm drain: Artificial storm drain can be added to LID area to divert runoff into specific locations to model runoff volume reduction of a specific LID control;

L – Others/project specific methods, such as use of IRAINBUILDING variable to turn on/off the runoff contribution from roofs to model green roof and rainwater harvesting LID controls.

2.4.2 Pairing of LID Controls and Model Parameters

The identified five basic LID controls include: 1) Bio Retention, 2) Bio Swale, 3) Pervious Pavement, 4) Rainwater Harvesting, and 5) Green Roof. The applicability of the FLO-2D modeling parameter/methods to the basic LID controls is summarized in Table 2.2. Note that this table shows the possible parameters that could be used for LID control modeling. The evaluation is preliminary and the conclusion could be different for a specific project and application.

Table 2.2 FLO-2D Modeling Parameters for LID Basic Controls

	Method No.	Parameter Name	LID Basic Control				
			Bio Retention	Bio Swale	Pervious Pavement	Rainwater Harvesting	Green Roof
			1	2	3	4	5
Potential Modeling Parameters	A	Grid elevation adjustment	X	X	X	X	
	B	Initial loss IA adjustment	X	X	X	X	X
	C	TOL value adjustment	X	X	X	X	X
	D	Infiltration rate adjustment	X	X	X	X	
	E	Limiting soil depth	X	X	X	X	
	F	Spatially variable rainfall	X	X	X	X	X
	G	Diversion by structure	X	X	X	X	X
	H	Boundary outflow grid	X	X	X	X	X
	I	Use of artificial WRF	X	X	X		X
	J	Use of artificial levee	X	X	X		
	K	Use of artificial storm drain	X	X	X	X	X
	L	Others/IRAIN-BUILDING				X	X

2.4.3 Parameter Adjustment Process for Simulation of LID Scenarios

The goal of the LID control evaluation is to develop a process that can be incorporated into the regional FLO-2D models. The FLO-2D modeling procedures for individual basic LID controls can be applied to regional modeling of LID scenarios. A LID scenario is defined as a LID practice system that includes multiple basic LID controls, accessories, and various land use participations. Detailed procedures for parameter adjustment from basic LID control modeling processes for simulation of LID scenarios will be discussed in Section 6. The main steps are summarized as follows:

Step 1: Determining LID design capacities for land uses (zoning);
Step 2: Estimating participation rate;
Step 3: Developing FLO-2D input data files based on the design capacities, individual basic LID control modeling results, and selected modeling parameters;
Step 4: Running the regional FLO-2D models and documenting the modeling results.

2.4.4 Model and Simulation Testing Protocols

The key to implementing LID controls into the FLO-2D model is the ability to quantify the impact of LID controls on an individual lot (parcel) basis. Typically, LID controls are independently implemented in relatively small areas – City R/W (parks, green streets, etc.), government R/W (schools, etc.), and private parcels (commercial, industrial, residential). The City of Tempe has provided the design team with GIS files defining the individual parcels within the City of Tempe (Model A area).

Several small area FLO-2D models were developed to evaluate the impact of LID controls on the rainfall/runoff response of a drainage area. The models being utilized are the Test Area model, Loma Vista Area model, and a Focus Area model with small grid (4 ft x 4 ft grid element size) and two blocks of neighborhood. Iterations may be run on these models much more quickly than on the regional models. Specifically, J2 is modeling individual LID control parameters within the small grid model in order to quantify the impact of the LID control on flood mitigation within a specific parcel area, and populating the methodologies to the Loma Vista Area model for regional LID practices.

A key operational function of the FLO-2D model is the conservation of volume. The model accounts for volume in several ways including: surface storage, surface flow, storm drain flow, and infiltration. Ultimately, the LID controls will impact the rainfall/runoff response of the watershed by reducing the volume of runoff from an individual parcel. The reductions in volume and peak flows were quantified in the model outflow hydrographs, model output summaries, and from placed floodplain cross sections.

3.0 COMMON LID CONTROLS IN THE SOUTHWEST

3.1 LID Controls, Accessories, and Systems

Many LID controls (also known as tools, practices, techniques, methods, or similar names, **control** is used in this report) have been developed and applied with similar hydrologic and hydraulic functions, but different shapes, materials, locations, and sometimes, with and or without add-ons (accessories). Some of the LID controls are actual combinations (systems) of several basic controls with accessories to improve their functions and capabilities. As discussed previously, five basic LID controls have been identified in this report from literature review. Table 3.1 listed the five basic LID controls and the similar controls with common and traditional names.

Table 3.1 LID Basic Controls and Their Similar Names

Five LID Basic Controls				
Bio Retention	Bio Swale	Pervious Pavement	Rainwater Harvesting	Green Roof
Similar names	**Similar names**	**Similar names**	**Similar names**	**Similar names**
Bioretention cell	Downspout disconnection	Pervious concrete	Active rainwater harvesting	Vegetated roof
Chicane	Grass swale	Pervious paving	Above ground cistern	Rooftop garden
Flow-through planter box	Linear vegetated swale	Porous asphalt	Below ground cistern	
In-ground planter box	Meandering vegetated swale	Soft paving	Rain cistern	
On-site bioretention basin	Vegetated channel	Stabilized aggregate	Rain tank	
Planter box		Structural grid system	Rain barrel	
Rain garden		Permeable paver system		
Raised planter box				
Regional bioretention basin				
Retention basin				

The LID controls can be classified based on their application locations, such as rain barrel, rain garden, rain tank, rain cistern, and bio retention for residential parcels and commercial properties; Chicane, planter box, bio retention, bio swales, and vegetated channel for street landscaping areas; Bio retention, bio swales, grass swale, and vegetated channel for public facilities; Pervious concrete, porous asphalt, soft paving, and pervious pavement for streets and parking areas; Rooftop garden, vegetated roof, and active rainwater harvesting for buildings.

The LID controls can also be classified based on their construction materials and shapes, such as grass, soil, mulch, asphalt, aggregate, sand, basin, swale, box, chicane, barrel, and tank.

The most useful classification of LID controls is based on their hydrologic and hydraulic functions: retention, detention, infiltration/recharge, storage/reuse, and conveyance (evapotranspiration is ignored for single storm event). Increasing infiltration rate is one of the major means by which LID controls are constructed to accomplish their functions. The purpose of classification for LID controls is to identify the basic LID controls for hydrologic and hydraulic modeling purposes. Table 3.2 listed the five basic LID controls and their hydrologic functions.

Table 3.2 LID Basic Controls and Hydrologic Functions					
Basic LID Control Name	Hydrologic Functions				
	Retention	Detention	Infiltration/ Recharge	Storage & Reuse	Conveyance
Bio Retention	X	X	X		X
Bio Swale		X	X		X
Pervious Pavement	X	X	X		X
Rainwater Harvesting	X			X	
Green Roof	X	X		X	

LID accessories are structures that are added or connected to basic LID controls to improve their hydrologic and hydraulic functions and capabilities. LID systems are combinations of one or more basic LID controls and accessories to improve and expand their hydrologic and hydraulic functions and capabilities, such as runoff collection, retention, detention, store, re-use, and conveyance. Table 3.3 shows the summary table for four (4) typical LID systems, possible combinations of basic controls and accessories.

Table 3.3 LID Systems, Basic Controls, and Accessories				
Typical LID Systems	On-Lot Treatment System	Green Parking System	Green Street System	Active Rainwater Harvesting
Basic Controls	Bio Retention, Bio Swale, Pervious Pavement, Green Roof	Bio Retention, Bio Swale, Pervious Pavement	Bio Retention, Bio Swale, Pervious Pavement	Rainwater Harvesting, Green Roof
Accessories	Downspout, Roof drain, Curb cut, underdrain	Concrete flush curb, Curb cut with sediment capture, Curb cut with sidewing, Grated curb cut, Standard curb cut, Underdrain, Wheelstop curb	Concrete flush curb, Curb cut with sediment capture, Curb cut with sidewing, Grated curb cut, Standard curb cut, Underdrain	Downspout, Roof drain

3.2 General Concepts of Basic LID Controls

The general concepts of the five (5) basic LID controls are illustrated in this sub-section. Most of the pictures and descriptions were from the report titled *Low Impact Development Toolkit* prepared for the City of Mesa. Appendix B1 includes a detailed design guidance manual developed by Rhode Island for LID roadway and parking lot design and design specifications for the basic LID controls developed by Virginia.

3.2.1 Bio Retention

Description:

Bio retention areas are small-scale, vegetated depressions designed to provide stormwater storage and filtration through engineered media. Using detention, sedimentation, filtration and adsorption, bio retention enhances the removal of contaminants from stormwater by both plants and soils. Bio retention can also incorporate pretreatment (i.e., vegetated filter strips, vegetated swales) allowing increased sedimentation and capture of debris from heavily trafficked areas.

Bio retention is applicable and encouraged for any landscape area to manage stormwater and provide an irrigation benefit for native vegetation. Bio retention areas can receive runoff from roofs, parking lots, roads, adjacent landscapes, athletic fields, agricultural areas and other areas where stormwater quantity and quality improvements are needed.

Bio retention can have various names for different materials, shapes and locations, such as rain garden, vegetated retention basin, bio retention cell, and planter box:

Vegetated Retention Basin, Rain Garden

- Shallow depressions in the landscape that include plants, a mulch layer and ground cover
- Healthy soils allow stormwater to infiltrate and supply plants with needed water, recharge groundwater and improve water quality
- Can accept runoff from a roof, other impervious surface or adjacent landscape
- Supports native landscape without the need for supplemental irrigation after plant establishment

Bio retention Cell

- Shallow depressions with a designed soil mix and plants adapted to the local climate and soil conditions
- Capture and infiltrate stormwater into the ground below the cell and have an overflow that carries excess stormwater to a discharge point

Bio retention Planters

- Do not infiltrate stormwater into the ground and include an underdrain
- Landscape planters that also store stormwater in porous planting soils and above the soil surface
- Planters may be raised above ground or can be set flush with or even below the ground surface
- They capture runoff from downspouts or overflow from cisterns
- There are several types of bio retention planters including:
    - Structural soils or Silva Cells
    - Raised flow-through planter boxes
    - In-ground planter boxes

Pictures:

Bioretention areas detain stormwater while enhancing the landscape.

Bioretention cells fit into constrained urban site.

Bioretention planters provide stormwater storage and promote healthy growth of trees and plants.

Benefits:

Bio retention (rain garden) has been shown to reduce peak flooding events when implemented throughout neighborhoods and communities. For every 100 square feet of bio retention, over $5,000 of benefits are created over the life of the bio retention as a result of increased property values, water conservation, shading of buildings and street pavement as well as other quality of life improvements (City of Tucson & WMG[1], 2015). Well-designed and constructed facilities receiving appropriate maintenance can increase infiltration rates over time by allowing natural processes to maintain soil porosity and increasing soil organic matter.

Limitations:

- Bio retention should be located at least 5-10 feet away from building foundations depending on relevant building codes. Locating bio retention less than 5 feet away from a building foundation should be carefully determined by local professional guidance and codes based on bio retention design, site conditions and soil types.
- In arid environments native plants must be established by irrigation system, water truck or by hand for the first 1-3 years. After the establishment period, plants will thrive on stormwater alone.
- Bio retention facilities must be maintained in order to achieve design performance.
- Experienced designers and construction managers are necessary to ensure bio retention performs as intended and can exceed design performance criteria.

Maintenance:

Regular maintenance is essential to maintain runoff infiltration capacity. Seasonal activities, especially around rainfall events, are necessary to ensure bio retention facilities are performing as expected. Sediment traps should be inspected before rainy seasons, native vegetation should be pruned for safety and healthy, natural plant growth, cuttings should be mulched on site and left in bio retention basin bottoms to increase soil organic matter, and undesirable plants not serving an infrastructure and aesthetic benefit should be removed completely including the roots. Sediment removed from sediment traps and basin bottoms can be disposed of onsite if sufficient area exists where sediment can be placed in landscaping areas, outside of basin bottoms and under mulch to maintain the site aesthetic. Excess sediment can be disposed offsite. Bio retention or adjacent areas should never be sprayed with chemicals, herbicides or pesticides, raked or mowed. These practices will degrade the functionality of the bio retention system. Leaving organic matter to decompose is an essential function to maintain and enhance system performance.

Costs:

Costs vary greatly depending on size, plant materials, and site considerations. Bio retention basins are generally less expensive when used in place of traditional stormwater conveyance. Watershed Management Group's experience is primarily with retrofit projects. Constructing and installing new landscapes and infrastructure with bio retention often results in a reduction of capital and maintenance costs by 10-20% relative to conventional infrastructure[2] Based on WMG's experience with bio retention retrofits for residential and commercial facilities, costs range from $0.85/gallon installed capacity for facilities installed in existing landscapes without

[1] Watershed Management Group

[2] Natural Resources Defense Council

major inlet structures needed to $2.30/gal when inlet structures such as curb cuts are necessary. Some variables that can increase costs significantly are engineered soils, underdrains, infiltration trenches and asphalt/concrete removal. For street and parking lot retrofits where concrete and asphalt removal and replacement was necessary, costs exceeded $12/gal of installed capacity.

Recommended Uses:
Bio retention is applicable and encouraged for any landscape area to manage stormwater and provide an irrigation benefit for native vegetation. Bio retention areas can receive runoff from roofs, parking lots, roads, adjacent landscapes, athletic fields, agricultural areas and other areas where stormwater quantity and quality improvements are needed. Bio retention area should be maximized before stormwater reaches traditional stormwater conveyance in order to reduce costly maintenance of in-ground infrastructure and to maximize water quality benefits and stormwater peak flow reductions.

Literature Referenced:
Low Impact Development Toolkit. City of Mesa. April 2015.

Natural Resources Defense Council. http://nrdc.org/water/commercial-value-green-infrastructure.asp.

Solving Flooding Challenges with Green Stormwater Infrastructure in the Airport Wash Area. Watershed Management Group. May 2015. http://watershedmg.org/document/gi-report-2015.

3.2.2 Bio Swale

Description:

Bio swales are shallow, open channels that are designed to reduce runoff volume through infiltration. Additionally, bio swales remove pollutants such as trash and debris by filtering water through vegetation within the channel. Swales can serve as conveyance for stormwater and can be used in combination with traditional curbs and gutters; however, when compared to traditional conveyance systems the primary objective of a bio swale is infiltration and water quality enhancement rather than conveyance. In addition to reducing the mass of pollutants in runoff, properly maintained bio swales can enhance the aesthetics of a site.

Bio swales are highly versatile stormwater Integrated Management Practices (IMPs) that effectively reduce pollutants. With a narrow width, bio swales can be integrated into site plans with various configurations and components. Ideal sites for bio swales include the right-of-way of linear transportation corridors and along borders or medians of parking lots. In heavily trafficked areas, curb cuts can be used to delineate boundaries. Bio swales can be combined with other basic and stormwater runoff Best Management Practices (BMPs) to form a treatment train to reduce the required size of a single IMP unit.

Bio swales can be utilized in place of conventional stormwater conveyance where flow velocities will not overwhelm the structural integrity of the established vegetation and rock structures. If space, runoff volumes and velocities permit, bio swales should meander in order to lengthen the flow path and slow runoff velocities. Bio swales can serve as connections between stormwater management features. Ideally, Bio swales would connect several different bio retention areas before discharging the overflow into a storm sewer inlet.

Vegetated Channel, Vegetated Swale

- Stormwater runoff conveyance systems that provide an alternative to piped storm sewers;
- Absorb low flows, direct runoff from heavy rains to bio retention facilities, then to storm sewer inlets;
- Improve water quality by enhancing infiltration of the first flush of stormwater runoff.

Pictures:

Vegetated swales accept stormwater for conveyance, storage and infiltration.

Benefits:

Bio swales can provide multiple benefits when designed to both convey and infiltrate runoff. Bio swales can reduce peak flooding events when implemented throughout neighborhoods and communities. For every 100 square feet of bio swale planted with native trees, over $5,000 of benefits are created over the life of the bio swale as a result of increased property values, water conservation, shading of buildings and street pavement as well as other quality of life improvements (City of Tucson & WMG, 2015). Well-designed and constructed facilities receiving appropriate maintenance can increase infiltration rates over time by allowing natural processes to maintain soil porosity and increasing soil organic matter.

Limitations:

- Space, velocity and volume considerations may limit applications in constrained spaces
- In arid environments native plants must be established by irrigation system, water truck or by hand for the first two warm seasons. After the establishment period, plants will thrive on stormwater alone.
- Bio swales must be maintained in order to achieve design performance.
- Experienced designers and construction managers are necessary to ensure bio swales perform as intended and can exceed design performance criteria.

Maintenance:

Regular maintenance is essential to maintain runoff conveyance and infiltration capacity. Seasonal activities, especially around rainfall events, are necessary to ensure bio swale facilities are performing as expected. Sediment in bio swales should be removed before rainy seasons, native vegetation should be pruned for safety and healthy, natural plant growth, cuttings should be mulched on site in order to increase soil organic matter of the adjacent landscape if areas outside of swales exist where flow velocities will not wash mulch away, and undesirable plants not serving an infrastructure and aesthetic benefit should be removed completely including the roots. Bio swales or adjacent areas should never be sprayed with chemicals, herbicides or pesticides, raked or mowed. These practices will degrade the functionality of the bio swale system. Leaving organic matter to decompose is an essential function to maintain and enhance system performance.

Costs:

Costs vary greatly depending on size, plant materials, and site considerations. Vegetated swales are generally less expensive when used in place of underground piping. Watershed Management Group's experience is primarily with retrofit projects. Constructing and installing new landscapes and infrastructure with bio swales often results in a reduction of capital and maintenance costs by 10-20% relative to conventional infrastructure[3]. Based on WMG's experience with bio swale retrofits for residential and commercial facilities, costs range from $0.85/gallon installed capacity for facilities installed in existing landscapes without major inlet structures needed to $2.30/gal when inlet structures such as curb cuts are necessary.

Recommended Uses:

Bio swales can serve as conveyance Bio swales should be planted with native grasses and groundcovers that can thrive when inundated with stormwater runoff, but will not create a flooding hazard by obstructing flow. Vegetation will allow for infiltration of low flows and retain soil in high flow events. Rock structures can enhance infiltration by slowing, spreading and sinking runoff into the soil. If space allows, rock structures and the bio swale can be shaped to meander and increase the length of the flow path for maximum flood reduction and water conservation benefit. Bio swales can receive runoff from roofs, parking lots, roads, adjacent landscapes, athletic fields, agricultural areas and other areas where stormwater quantity and quality improvements are needed.

[3] Natural Resources Defense Council

Literature Referenced:
Low Impact Development Toolkit. City of Mesa. April 2015.

Natural Resources Defense Council. http://nrdc.org/water/commercial-value-green-infrastructure.asp.

Solving Flooding Challenges with Green Stormwater Infrastructure in the Airport Wash Area. Watershed Management Group. May 2015. http://watershedmg.org/document/gi-report-2015.

3.2.3 Pervious Pavement

Description:

Pervious pavement can have various names for different materials, shapes and locations, such as:

Stabilized aggregate - a mixture of compacted stone aggregate and a binder;

Porous asphalt - standard asphalt pavement in which the fines have been screened and removed, creating void spaces that make it highly permeable to water;

Porous concrete - single size, screened aggregate consists of a special mix design with void spaces that make it highly permeable;

Structural grid systems - consist of plastic, concrete or metal interlocking units that allow water to infiltrate through large openings filled with aggregate stone, or topsoil and turf grass;

Permeable pavers - precast concrete unit pavers designed to be set on a compacted base and highly permeable setting bed with joints filled with sand or fine gravel.

Pervious pavement allows for percolation of stormwater through subsurface aggregate and offers an alternative to conventional concrete and asphalt paving. Typically, stormwater that drains through the pervious surface is allowed to infiltrate underlying soils and excess runoff drains through perforated underdrain pipes. Pervious pavement can be designed as a self-treating or self-retaining area.

The use of pervious pavement is encouraged for sites such as parking lots, driveways, pedestrian plazas, rights-of-way, and other lightly traveled areas. Numerous types and forms of pervious pavers exist and offer a range of utility, strength, and permeability. Pervious pavement must be designed to support the maximum anticipated traffic load but should not be used in highly trafficked areas. For designs that include infiltration, surrounding soils must allow for adequate infiltration. Precautions must be taken to protect soils from compaction during construction. Pervious pavement is typically designed to treat storm water that falls on the pavement surface area and run on from other impervious surfaces. It is most commonly used at commercial, institutional, and residential locations in area that are traditionally impervious. Pervious pavement should not be used in high-traffic areas.

Pictures:

Stabilized aggregate reduces storm runoff from low-traffic paving areas.

Porous asphalt paving is a runoff-reducing in paving areas and driveways.

Porous concrete can reduce runoff sustaining in sidewalks and plaza areas.

Structural grid paving reduces runoff in parking areas and firelanes.

Permeable paving is an attractive way to provide runoff reduction in paving and pedestrian areas.

Benefits:
Pervious pavements provide stormwater runoff reduction through infiltration, reducing ponding and flooding.

Limitations:

- Maintenance may be a challenge in areas with adjacent landscapes that are not stabilized, high airborne dust concentrations and/or sediments in stormwater.
- Stabilized aggregate and engineered soils are required to achieve stormwater infiltration benefits often leading to higher costs than for landscape based LID practices where native soils and plants provide and support design infiltration rates.
- Pervious pavements do not provide multiple benefits unless infiltrated water meets tree irrigation needs.
- Not appropriate for cold climates due to frost heave.

Maintenance:
Regular maintenance is essential to maintain runoff infiltration capacity. Specialized equipment is required to remove accumulated materials that clog porous surfaces with vacuuming or pressure washing.

Costs:
Based on research from the EPA the range of costs are:

Pavement	Paved Area (sq ft)	Quote ($)	Quote ($)	Quote ($/sq yd)	Quote ($/sq yd)	Quote ($/Sq ft)	Quote ($/sq ft)
		Highest	Lowest	Highest	Lowest	Highest	Lowest
Hot Mix Asphalt	36,225	98,600	92,620	24.50	23.01	2.72	2.56
Porous Asphalt	5,328	28,650	18,352	4,840	31.00	5.38	3.44
Porous Pavers	5,328	67,960	61,755	114.80	104.32	12.76	11.59
Porous Concrete	7,988	63,200	53,919	71.21	60.75	7.91	6.75

Recommended Uses:
Pervious pavement materials are recommended for commercial and residential applications where the capacity of landscape areas is not available or sufficient to handle desired runoff volumes. If possible, grade soil sub-grade below pervious pavement to direct infiltrated water from pervious surfaces to landscape root zone to achieve multiple benefits from trees.

Literature Referenced:
Low Impact Development Toolkit. City of Mesa. April 2015.

Pervious Pavement Research--Edison New Jersey, Amy Rowe, EPA National Risk Management Research Laboratory. http://nyccpc.org/Documents/2010/RoweNYCCPC.pdf.

University of Maryland Extension Fact Sheet. Pervious Pavement Fact Sheet Information for Howard County, Maryland Homeowners. Accessed Oct 8, 2015.

3.2.4 Rainwater Harvesting

Description:

Rain Tank, Cistern, Rain Barrel

- An aboveground rain tank captures stormwater runoff, often from a rooftop, and stores the water for later use
- A rain tank consists of the following main components including a gutter system that collects runoff from the rooftop and directs it into the rain tank for later use, a rain head to prevent large debris from entering the tank plumbing system, a first-flush to capture the first flow of dirty water and sediment from a roof, an overflow pipe that allows excess runoff to leave the rain tank in a controlled manner, and an outlet pipe that distributes water to a garden or landscape by gravity or pump from the bottom of the rain tank
- If rain tanks are utilized for potable water storage, test the source water from the rain tank, utilize conveyance plumbing designed for drinking water standards, treatment should include a sand filter, carbon filter, ultraviolet disinfection and can include a reverse osmosis filter for extra precaution
- An underground rain tank may be preferable where surface space is limited
- Rain tanks may be constructed of various materials including plastic, cinder blocks, reinforced concrete, fiberglass or steel.

Rain tanks work best harvesting stormwater off of relatively clean surfaces like building rooftops. Rain tanks can be used to store stormwater off of other surfaces when landscape space is limited and appropriate filtration strategies and maintenance are planned. Rain tanks work well in residential, commercial and industrial settings.

Pictures:

Cisterns can store rainwater to be re-used for future landscape irrigation.

Underground cisterns provide storage areas for rainwater reuse.

Benefits:

Rain tanks provide storage of stormwater for use during dry periods. Rain tanks can be utilized for a variety of needs including outdoor uses, indoor non-potable water needs and drinking water. Rain tanks function most effectively when designed as an integrated system that includes bio swales and bio retention for managing rain tank overflows and harvesting runoff from non-roof surfaces.

Limitations:

- Rain tanks are the most costly storage option per gallon of capacity;
- If tanks are not utilized in between storm events, stormwater harvesting capacity may be limited or non-existent unless a bleed pipe is utilized to maintain tank capacity;
- Water use requires regular human interaction with systems, costly automated systems and generally has many parts that can fail if not well-maintained.

Maintenance:

- Regularly check the gutters and rain head to make sure debris is not entering the tank;

- Inspect the screens annually to make sure debris is not collecting on the surface and that there are not holes allowing mosquitoes or other insects to enter the tank;
- Clean the inside of the cistern twice a year to prevent buildup of debris. Clean out debris twice a year, preferably prior to the beginning of each rainy season;
- Check screens and tank fittings are sealed to prevent mosquito breeding;
- Ensure first-flush diverter is functioning properly;
- Check gutter connections every three to four months and after intense rainfall to check for leaking or damage;
- Check gravity feed irrigation system and/or maintain pumps or filters in accordance with manufacturer's recommendations.

Costs:
Costs for rain tanks vary greatly depending on size, material, site conditions, tank uses and whether the tank is above ground or underground. Smaller tanks have a higher $/gal cost. Small (less than 800 gallons) above ground tanks can cost $1.5+/gal installed. Larger (greater than 800 gallons) above ground tanks typically range from $1-1.5/gal installed. Underground tanks are typically $2+/gal installed.

Recommended Uses:
Rain tanks work best when site goals include irrigating high water use landscapes, food production, meeting indoor water demand, and/or offsetting or eliminating municipal/ groundwater sources. If flood mitigation is a goal, an appropriately designed bleed piped should drain to a bio swale and/or bio retention to ensure there is rain tank capacity to store subsequent storm event flows.

Literature Referenced:
Low Impact Development Toolkit. City of Mesa. April 2015.

3.2.5 Green Roof

Description:

Green Roof or Vegetated Roof

- A green roof or Xeriscape living roof is when the roof of a building or structure is at least partially covered with a growing medium and vegetation planted over a waterproofing membrane. It may also include a root barrier, drainage mat and irrigation system.
- There are two types of green roofs: Intensive and Extensive. The difference is in the depth of soil and the ability to support simple groundcover planting (extensive, 3-5 in of soil) versus larger materials such as trees and shrubs (intensive, 5-24+ in of soil).
- Green roofs provide stormwater storage and absorption, reduce runoff from buildings, and insulate buildings from solar gain and heat loss.

Green roofs are not common in the arid southwest due to construction and plant establishment challenges. The Tempe Transportation Center and University of Arizona College of Architecture, Planning and Landscape Architecture are two examples of established intensive green roofs. A few residential applications exist in Tucson and Phoenix. Green roofs have worked in residential, commercial and industrial settings.

Pictures:

Green roofs store and utilize stormwater to reduce runoff from building sites.

Benefits:
Green roofs serve to slow roof runoff, filter pollutants and provide additional benefits from habitat creation as well as reductions in urban noise, heat island, local temperatures and building energy consumption. Green roofs have also been shown to extend the life up to 200% of existing roof material.

Limitations:

- Retrofits can be difficult and costly due to structural roof requirements both intensive and extensive green roofs;
- Professionals must be consulted for the design and construction of the green roof. A qualified architect, structural engineer, landscape architect and facility maintenance personnel (commercial) are critical to the success of a green roof project;
- The plant establishment period is critical to ensure survival in the harsh environment;
- Roofs must be protected from retained plant moisture to eliminate roof damage.

Maintenance:

- Vegetation will require supplemental irrigation and only very hardy plants should be used in our desert environment. Depending on whether the green roof is extensive or intensive, required plant maintenance will range from two to three yearly inspections to check for weeds or damage, to weekly visits for irrigation, pruning, and replanting;
- Both plant maintenance and maintenance of the waterproofing membrane are required;
- To ensure continuity in the warranty and the maintenance requirements, the building architect, structural engineer and/or owner should specify and maintain everything up to and including the waterproof membrane. The green roof designer and installer are only responsible for those items above the waterproof membrane, including soils, drainage and plantings.

Costs:
Data from other climates show a well designed and installed extensive green roof can cost \$10-12/ft^2. Intensive green roofs can cost \$33-220/ft^2. Costs vary widely based on the design, building type, use of reclaimed materials, retrofit or new construction and climate.

Recommended Uses:
Green roofs work well in urban environments where existing landscape area is minimal and visual or physical access to the site is possible to enjoy the green roof environment. Green roof retrofits are more cost effective for extensive green roofs due to less structural roof requirements and intensive green roofs can more easily be incorporated into new construction and design. Stormwater benefits can be achieved more cost effectively by other LID controls, however, the benefits of habitat creation as well as reductions in urban noise, heat island, local temperatures and building energy consumption.

Plants that work well in Tempe:
Rocky Point Ice Plant (Malephora lutea), Slipper Plant (Pedilanthus macrocarpus), Red Yucca (Hesperaloe parviflora), Bear Grass (Nolina microcarpa) and Candelilla (Euphorbia antisyphilitica).

Plants that worked well in Tucson:
Red Yucca (Hesperaloe parviflora), Fairy Duster (Calliandra eriophylla), Dogweed (Dyssodia pentachaeta).

Literature Referenced:
Low Impact Development Toolkit. City of Mesa. April 2015.

Tempe Transportation Center: http://www.greenroofs.com/projects/pview.php?id=935.

3.3 General Concepts of Basic LID Accessories

The general concepts of selected LID accessories are illustrated in this sub-section. Most of the pictures and descriptions were from the report titled *Low Impact Development Toolkit* prepared for the City of Mesa. More LID accessories can be found in Appendix B2 which includes a detailed LID design manual for urban areas developed by University of Arkansas.

Standard Curb Cut

Description:

Curb cuts are openings created in a curb to allow stormwater from an impervious surface, such as roads, parking lots, or hardscape areas, to flow into a lower landscaped storage and LID control area. The curb cut is a useful tool for retrofitting existing development with LID practices without major reconstruction. Since curb cut openings are perpendicular to the flow of stormwater on the street, they will usually collect only a portion of the water flowing along the gutter. If attenuating stormwater flows along the street is the goal, place multiple curb cuts at intervals along the street.

Pictures:

Curb cuts control stormwater flow from streets to LID facilities.

Installation and Maintenance:

Openings should be at least 18 inches wide, but up to 36 inches is preferred for ease of maintenance. Openings should be at low points and spaced based on amount of water being received along curb, and the area available for detention, infiltration, and access to overflow systems. The curb cut can either have vertical or angled sides. The design intent is to create a smooth transition from the paved surface to full curb height.

Curb cuts work well with relatively shallow stormwater facilities that do not have steep side slopes that might erode. Set the elevation of the bottom of the curb cut to maximize flow into the landscape area. A drop in grade should occur between the curb cut entry point and the finish grade of the landscape area to allow for passage of sediment. Small amounts of hand placed rip-rap can be used on the LID facility side of the curb cut opening to reduce the potential for erosion in landscaped areas.

Regularly clear curb cuts of any debris and sediment that prevents the free flow of stormwater into LID facility (1-2 times per year and after major storm events). Periodically check rip rap areas for signs of erosion damage. Repair and reinforce as necessary (annually and after major storm events).

Curb Cut with Sidewings

Description:

The sidewing addition to curb cut conveys stormwater a greater distance, and can reduce the potential for erosion behind the curb or close to the paved surface.

Pictures:

Curb cuts direct stormwater from street to landscape areas.

Installation and Maintenance:

Sidewings work well to guide stormwater greater distances and with stormwater facilities that have steep side slopes. Openings should be at least 18 inches wide, and sidewings can be parallel or tapered.

Slope the bottom of the curb cut and trench toward the landscape area. The slope should be flat enough to keep flow velocities low and steep enough to keep sediment moving (between 1% and 5% slope). A drop in grade should occur between the curb cut entry point and the finished grade of the landscape area to allow for passage of sediment. Small amounts of hand placed rip-rap can be used outside the curb cut opening to reduce the potential for erosion in landscaped areas.

Regularly clear curb cuts and sidewings of any debris and sediment that prevents the free flow of stormwater into LID facility (1-2 times per year and after major storm events). Periodically check rip rap areas for signs of erosion damage. Repair and reinforce as necessary (annually and after major storm events).

Grated Curb Cut

Description:

Grated curb cuts allow stormwater to be conveyed into LID area under a pedestrian walkway. Curb-cut openings are described in previous sections to allow stormwater from impervious surfaces to flow into a LID area. The grated curb cut is a useful tool for urban areas where there is heavy pedestrian traffic and the need for handicap accessible routes adjacent to streets and parking areas.

Grated curb cuts should only be used where there is not enough vertical distance to install a scupper. Where they are used, only decorative heavy duty, accessible, precast gratings should be permitted.

Pictures:

Grates allow stormwater to pass through while proving an accrossing pedestrian route.

Installation and Maintenance:

The grated curb cut opening should ideally be 18 inches wide; enough to minimize the potential for clogging. Grates should be compliant with the Americans with Disabilities Act (ADA) and have adequate slip resistance. Grates should be anchored in a way that deters removal or theft.

A drop in grade should occur between the grated curb cut channel and the finish grade of the landscaped area to allow for the passage of sediment. Permanent or temporary erosion control may be necessary where concentrated runoff from the channel is deposited into the landscaped area.

Regularly clear grated curb cuts of debris and sediment that may prevent the free flow of stormwater (1-2 times per year and after storm events). Periodically check for damage to grate and structural support system that may cause ponding of water or impede accessible pedestrian routes. It may be necessary to remove grates to clear sediment and debris.

Curb Cut with Sediment Capture

Description:

Sediment removal poses a considerable challenge in the maintenance of LID control area. In the arid Southwest, high proportions of bare soil are common, resulting in high rates of erosion and sedimentation. Sediment capture can address this issue. Sediment catchments capture and collect sand and fine soils at the entrance to bio retention areas, removing them from stormwater and allowing periodic removal. Sediment removal can significantly extend the functional life of these features.

Pictures:

Sediment capture can be open or covered.

Installation and Maintenance:

Use sediment capture in areas where higher than normal sediment loads are expected. Excavate at least 12 inches from the inside of the curb cut, and at least 2 feet square by 8 inches deep. The capture device can either be open or covered with a grate. A concrete curb, or steel edge, several inches in height, may be used to separate the capture area from the adjacent landscape detention area or basin, and anchor the grate.

A berm, several inches in height, may be used to separate the capture area from the adjacent LID area or basin. Plant the berm with native groundcover plantings to stabilize it and allow it to filter stormwater pollutants.

Check sediment capture device to ensure that the stormwater inlet does not become blocked (before and after rainy seasons and after large storm event). Regularly remove sediment from the bottom of the facility (frequency depends on sedimentation rates, but at least once a year). Check apron, slopes, edges, etc. for erosion and repair/reinforce as needed (annually and after storm events).

Concrete Flush Curb

Description:

Concrete flush curbs allow stormwater to runoff impervious surfaces directly into LID control areas and stormwater facilities. Stormwater flow is distributed more evenly which reduces the potential for erosion and clogging along a pavement edge.

Pictures:

Flush curbs allow stormwater to sheet drain to landscape areas.

Installation and Maintenance:

Top of concrete curb should be installed flush with the pavement surface, with allowances for subgrade compaction and future settlement. A drop in grade should occur between the top of the flush curb and the finished grade of the landscaped area to allow for passage of sediment and debris to drop out.

Utilize temporary erosion control measures when seeding or planting adjacent areas to reduce the potential for erosion. A wider surface area and contrasting color for the flush curb provides an important visual cue when used on roads, driveways and bicycle paths. This tool will be considered on a case by case basis for street rights-of-way.

Check the flush curb for signs of damage or settlement causing ponding or concentration of stormwater runoff. Check landscape edge condition for signs of rilling or erosion and repair or reinforce as needed (annually). Remove sediment and debris from landscape area outside of flush curb that may cause water to pond or backup.

Wheelstop Curb

Description:

Wheelstop Curbs are formed sections of curb with gaps between them. They allow stormwater from adjacent impervious surfaces, like parking lots, to flow into adjacent LID control areas.

In flush, or no curb parking areas, poured-in-place wheelstop curbs can be used to define openings and protect LID control areas.

Pictures:

Wheelstops allow sheet drainage to pass into landscape areas.

Installation and Maintenance:
Space poured-in-place wheel stop curbs as needed for parking/traffic conditions while allowing water to flow into LID areas. Poured-in-place wheel stop curbs are most common in parking lot applications, but they can also be applied in certain street conditions.

Provide a minimum of 6 inches of space between the poured-in-place wheelstop curb edge and edge of asphalt paving to provide structural support for the wheel stop. Securely anchor poured-in-place wheelstop curbs using foundations or other support to ensure that they resist vehicle impact and overturning. A concrete flush curb is advised along the edge of pavement for structural support of poured-in-place wheel stop curbs and visual demarcation of parking area or driveway edge.

Poured-in-place wheelstop curbs have similar maintenance requirements as other poured concrete curbs. Unless they are firmly anchored they can be dislodged creating unsightly and dangerous conditions. They should be check regularly for cracking and settlement and repaired or replaced as necessary.

Downspout
Description:
Downspout is used to direct rainwater from the rooftop into a LID control instead of into a piped system or into the street. Downspouts can direct stormwater to LID control where it is stored and used to irrigate landscape plants or infiltrate into the ground.

Pictures:

Installation and Maintenance:

Direct downspout extensions away from building foundations or adjacent properties to avoid structural damage or nuisance flooding. Firmly anchored splash blocks or hand placed rock can be installed to direct downspout drainage to LID areas.

Ensure that the offsite overflow is sufficiently lower than the building floor elevation to reduce the potential for building flooding.

Clean gutter at least twice a year, and more often if there are overhanging trees. Make sure gutters are pitched to direct water to downspouts. Caulk leaks and holes. Make sure roof flashing directs water into the gutters. Look for low spots or sagging areas along the gutter line and repair with spikes or place new hangers as needed.

Check and clear elbows or bends in downspouts to prevent clogging. Each elbow or section of the downspout should funnel into the one below it. All parts should be securely fastened together. Maintain landscaping so that there is positive drainage away from all structures. Don't build up grade, soils, groundcover mulches, or other materials near the building that might inhibit positive drainage.

Roof Drain

Description:

Roof Drain is used to help collect and convey runoff from green roof LID control area into rain tanks, cisterns above/below ground or piped systems.

Pictures:

Installation and Maintenance:

Roof Drain should be located at lower spots to collect runoff from the green roof and firmly anchored and tightly sealed to avoid leakage.

Ensure that the pipes are connected to downspouts and into rain tanks, cisterns above/below ground or piped systems to either store the runoff or irrigate vegetated areas.

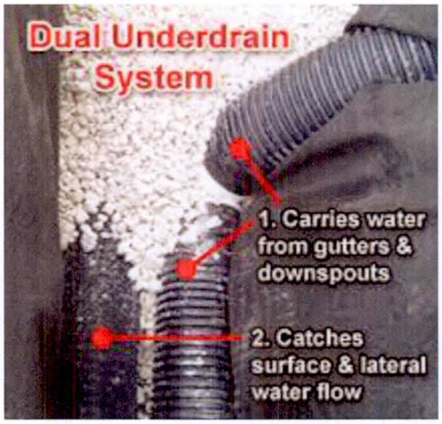
Clean inlets at least twice a year, and more often if there are overhanging trees. Check and clear elbows or bends in downspouts to prevent clogging.

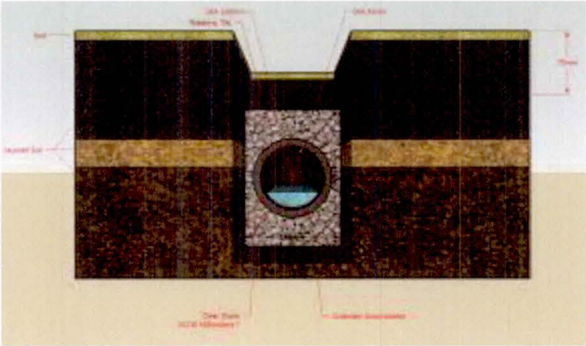
Underdrain

Description:

A perforated pipe, typically 4-6 inches in diameter placed longitudinally at the invert of a bio retention, bio swale, or pervious pavement LID control for the purposes of achieving a desired discharge rate or runoff volume reduction.

Pictures:





Installation and Maintenance:

Pipe underdrain should be installed with trench. The perforated pipe shall be bedded on 4 in coarse aggregate material and carefully backfilled with the remaining coarse aggregate cover material to 6 in above the top of pipe.

Clean outlets at least twice a year and after each major storm event.

4.0 FLO-2D MODELING PROCEDURES FOR INDIVIDUAL LID CONTROLS

4.1 FLO-2D Model for the Focus Area and LID Modeling Methods

The primary objective of the Focus Area modeling is to develop detailed hydrologic and hydraulic modeling procedures for basic LID controls in order to determine the appropriate FLO-2D modeling processes for regional modeling. The FLO-2D model for the Focus Area covers two blocks of neighborhood with an area of about 21 acres which forms a relatively closed drainage watershed (minimal off-site inflows). The Focus Area model has 4 ft x 4ft grid size and 56,693 total number of grid. The optimal grid size should be estimated based on the topographic mapping accuracy (grid size ~ mapping accuracy/surface slope), size of the modeling area, types of LID controls and accessories, and modeling objectives.

Appendix C0 includes the base model input and output data files, and Exhibit A shows the Focus Area boundaries and modeling results for the base model.

As discussed previously and documented in previous memos, the proposed possible modeling methods for five basic LID controls are summarized in Table 4.1.

Table 4.1 FLO-2D Modeling Methods for LID Basic Controls

LID Basic Control	Possible Modeling Methods			
	Grid elevation adjustment	Initial loss IA adjustment	Infiltration rate/Soil depth adjustment	Use of artificial storm drain
Bio Retention	X	X	X	X
Bio Swale	X	X	X	X
Pervious Pavement	X	X	X	X
Rainwater Harvesting		X	X	X
Green Roof		X		X

In addition to grid elevation adjustments for areas with significant retention and detention volume, infiltration rate and limiting soil depth adjustments were used for increased infiltration capacities of LID controls on the computation of runoff reduction. Initial loss IA adjustment was used for the modeling of LID controls of Rainwater Harvesting and Green Roof. Artificial storm drain system was used for modeling bio swale and pervious pavement with underdrain systems.

The advantages of FLO-2D models with smaller grid cells (in this study, 4 ft x4 ft grids, high accuracy of topographic mapping required) are:

1) For small LID areas, the hydrologic processes, such as topographic differences (grid elevation adjustments), infiltration rate and limiting soil depth changes, surface runoff movement within bio swales, etc. can be modeled;

2) With the small grid FLO-2D model, higher resolution hydraulic modeling parameters can be obtained, such as flow depths and velocities within streets and bio swales;
3) Runoff collection and diversion processes by LID accessories with small dimensions (typically, 18 in to 48 in long), such as curb cut, flush curb, curb cut with sidewing, wheelstop curb, etc. can be represented and modeled adequately.

4.2 FLO-2D Modeling Procedures for Bio Retention

In addition to grid elevation adjustments for the grids within the Bio Retention areas, spatially varied infiltration rates and limiting soil depths method was applied by the FLO-2D model to evaluate the impact of Bio Retention on the study area hydrology and hydraulics. The detailed steps are:

Step 1: Determining Parcel Design Capacities for LID Controls

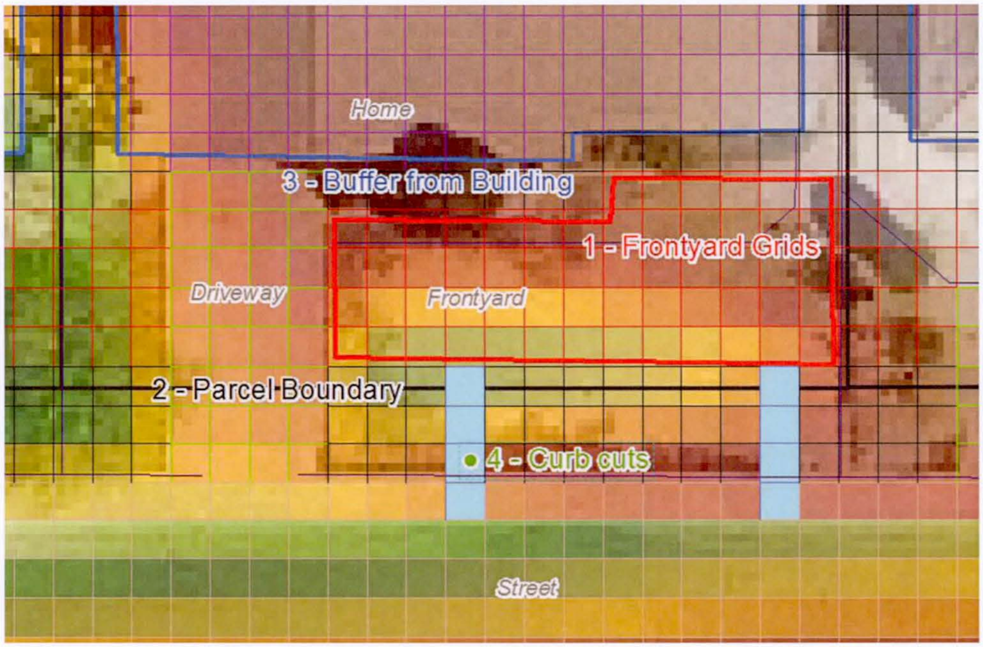
In general, total LID design capacities for all the parcels within the modeling area should be estimated based on land uses and sizes according to land use zoning and the City's on-site retention requirements (i.e., utilize the 100-year, 2-hour on-site retention requirement as a practical upper limit) which will be demonstrated in Section 6. In the Focus Area modeling for the bio retention LID control, the parcel specific bio retention application areas were developed based on parcel pervious areas within the modeling areas as shown in Exhibit B1. The total number of grids within Bio Retention area is 2436. A typical bio retention LID control has two layers of areas where storm water can be stored: top open basin and bottom coarse permeable material for increased infiltration. For Focus Area model, the bio retention basin depth and infiltration depth of 6 in was modeled with total bio retention design capacity of 0.89 ac-ft.

Step 2: Developing FLO-2D Input Data files

The steps for revising the FLO-2D input data files are as follows starting with a working base model:

1) Grid Assignment
   a) Bio retention grids - Grid assignment for the bio retention began with identifying the front yard (No. 1 in the following map) grids. These grids were then narrowed down to those that were contained within the parcel (No. 2 in the following map). Grids adjacent to a building were also ignored from the selection (No. 3 in the following map).

   b) Accessory grids - Grids were then assigned for curb cuts to help route flow to the bio retention areas. The curb cut grids (No. 4 in the following map) were placed on the grid adjacent to the lowest roadway grid and extended to the bio retention area. Each bio retention area was given 2 connections to the street.



2) Input Data Files

a) FPLAIN.DAT – The bio retention area grids were grouped by unit; each front yard was treated separately. Elevations to be applied across all grids per front yard were determined by subtracting 0.5 ft from the low grid on roadway elevation to create the top open basin. Each bio retention grid was also assigned an N-value of 0.1 to both represent increased vegetation and reduce simulation runtime.

Curb cut grids attributed to the same parcel were all given the same elevation which was approximately the lowest street grid elevation adjacent to the property rounded down to the nearest tenth.

b) INFIL.DAT – The bio retention area grid infiltration parameters were modified as if they were a loamy sand soil amendment with an additional 6 in of infiltration-loss capacity with the following modified parameter values:

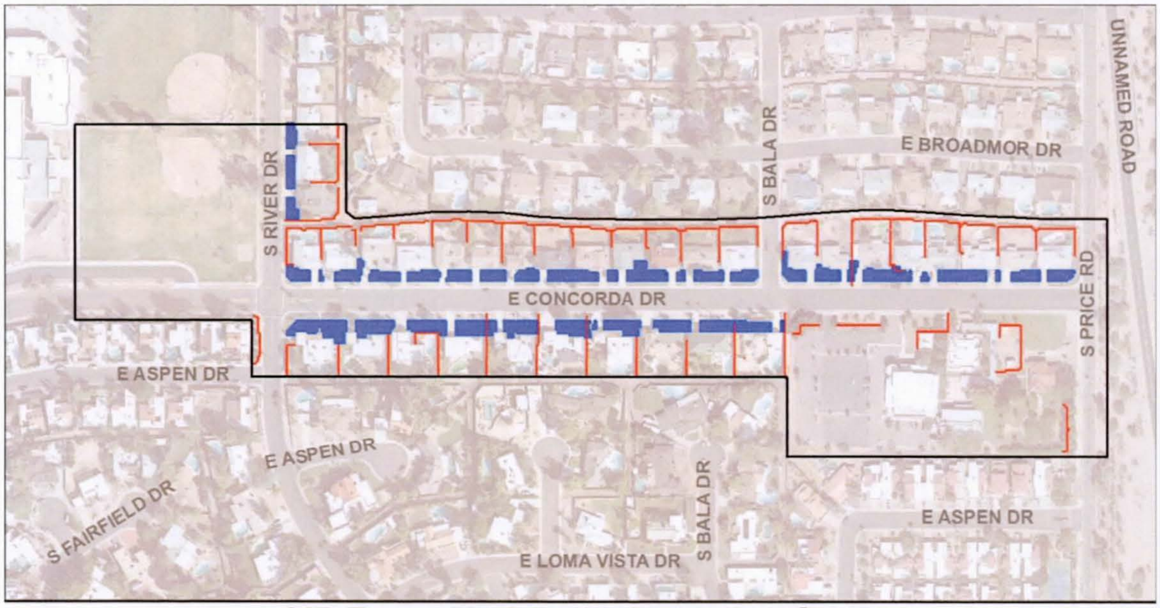
i) HYDC – The hydraulic conductivity, in inches/hr: A value of 1.2 was used based on the 1995 FCDMC Drainage Design Manual, Table 4.2;
ii) SOILS – The soil suction head, in inches: a value of 2.4 was used based on the 1995 FCDMC Drainage Design Manual, Table 4.2;
iii) DTHETA – The volumetric soil moisture deficit, a coefficient that determines available volume within a depth of soil: a value of 0.3 was used based on the 1995 FCDMC Drainage Design Manual Figure 4.3;
iv) ABSTRINF - The initial abstraction in inches: a value of 0 was used for the bio retention area grids for the purpose of estimating infiltration volume;
v) RTIMP – A coefficient representing the imperviousness of the surface: a value of 0 (no impervious area within bio retention areas) was used to allow full infiltration;

vi) SOILD – The limiting soil depth in feet: A value of 1.667 was added on top of the original limiting soil depth used. This was determined by using our design depth of 6 in divided by DTHETA (0.3) and converted to feet (0.5 ft/0.3 = 1.667 ft).

Step 3: Running FLO-2D Models and Documenting Results

A base model (Model LID2.1) was developed without any LID applications (100-year, 6-hour storm model) and a model with Bio Retention LID control (Model LID 6.5) for all parcels was developed to simulate the effects of LID applications. The summary modeling results were documented in Table 4.2a.

The total LID design volume is the LID system capacity within the modeling area. The surface flow comparison values were from "SUMMARY.OUT" file and the storm drain flow comparison values were from SWMM.RPT file as shown in Table 4.2a and the numbers used were highlighted (These files were also included in Appendix C1). The LID control grids and their close-up map are shown in the following.



LID Focus Model - Bio Retention Grids

Model Boundary — Walls — Bio Retention

N

1 inch = 400 feet

LID Focus Model - Bio Retention Grids

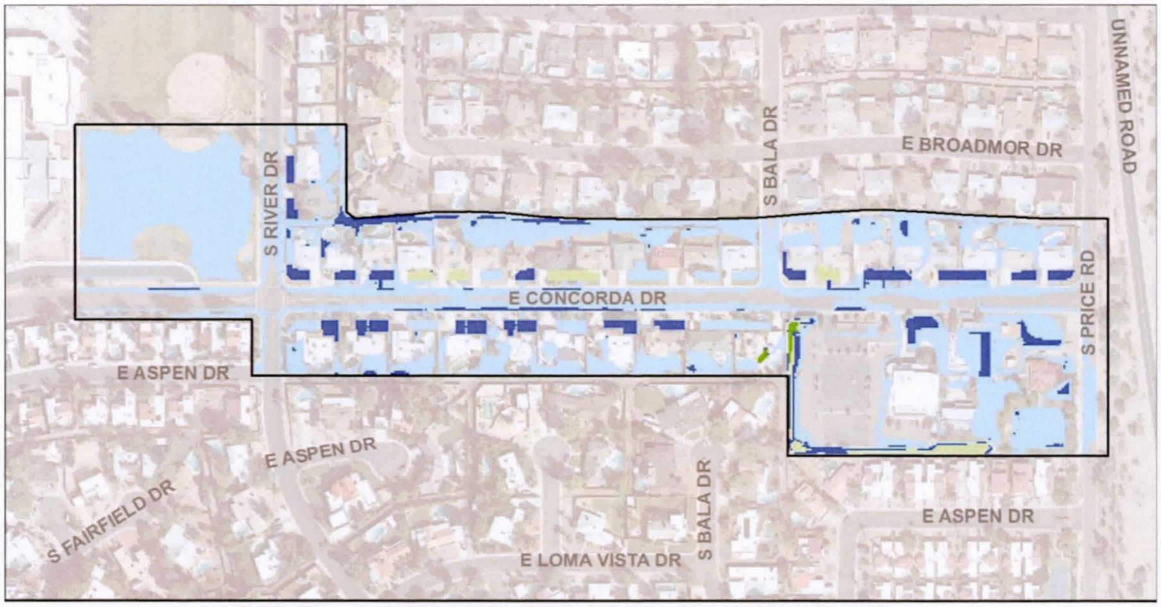
Model Boundary — Walls — Bio Retention

N

1 inch = 100 feet

Table 4.2a Bio Retention Modeling				
Output File Names	Parameter Names	Parameters	FLO-2D Models	
			LID 2.1	LID 6.5
			Base	Bio Retention
SWMM RPT	Outflow (Outfall node I338)	Qp (cfs)	8.58	4.70
	Wet weather inflow	V (acft)	1.19	0.64
	Return flow	V (acft)	0.04	0.00
SUMMARY OUT	Rainfall Volume	V (acft)	4.37	4.37
	Infiltration & interception	V (acft)	0.93	1.32
		%	21	30
	Floodplain storage	V (acft)	1.47	1.83
		%	34	42
	TOL storage	V (acft)	0.07	0.07
		%	2	2
	Floodplain outflow	V (acft)	0.76	0.58
		%	17	13
	Stormdrain (FLO-2D to SWMM)	V (acft)	1.23	0.64
		%	28	15
	Return flow (SWMM to FLO-2D)	V (acft)	0.03	0.00
Check	Sum of volumes	V (acft)	4.36	4.37
	Volume captured	V (acft)	-	0.75
	Target volume capture	V (acft)	-	0.89
	Utilization of Bio Retention volume	%	-	84.3
	Bio Retention grids	2436		
	Elevation difference volume	0.447	acft	
	Infiltration depth added	0.5	ft	
	Infiltration volume	0.447	acft	
	Total volume capacity	0.89	acft	

The maximum flow depth for the focus area and a close-up area are shown below.



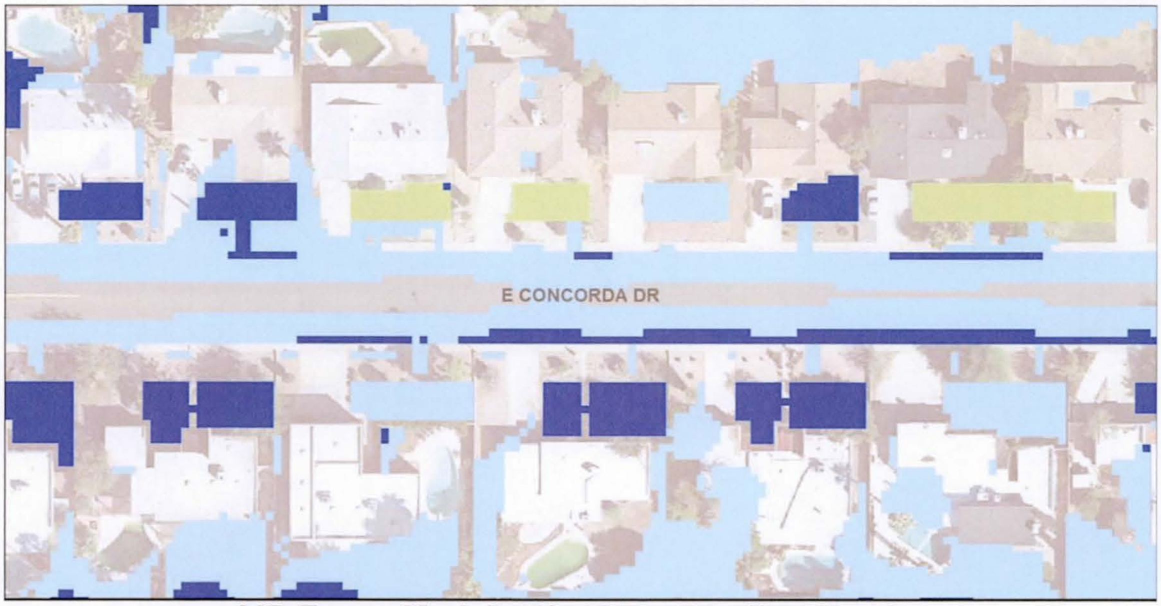
LID Focus Model - Bio Retention Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 400 feet



LID Focus Model - Bio Retention Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 100 feet

```
                    Abbreviated SUMMARY.OUT FILE

               Pro Model - Build No. 15.02.10
=================================================================
                          *** INFLOW (ACRE-FEET) ***
TOTAL POINT RAINFALL:                                  2.5200 INCHES
                                                    WATER
RAINFALL VOLUME                                        4.37
SURFACE WATER INFLOW HYDROGRAPH                      0.00
                                                  ---------
INFLOW HYDROGRAPHS + RAINFALL                          4.37
=================================================================
                          *** SURFACE OUTFLOW (ACRE-FT) ***
OVERLAND INFILTRATED AND INTERCEPTED WATER        1.12 INCHES
          OVERLAND FLOW                             WATER
WATER LOST TO INFILTRATION & INTERCEPTION              1.32
FLOODPLAIN STORAGE                                     1.83
OVERLAND STORAGE DUE TO TOL                            0.07
FLOODPLAIN OUTFLOW HYDROGRAPH                          0.58
                                                  ---------
FLOODPLAIN OUTFLOW, INFILTRATION & STORAGE             3.72
TOTAL SURFACE OUTFLOW AND STORAGE                      2.41
=================================================================
          *** FLO-2D STORM DRAIN EXCHANGE VOLUME (ACRE-FT) ***
FLO-2D TO SWMM THROUGH INLETS                          0.64
SWMM TO FLO-2D FROM RETURNING FLOW                     0.00
SWMM TO FLO-2D FROM OUTFALL                            0.00
FLO-2D TO SWMM FROM OUTFALL                            0.00
                                                  ---------
NET VOLUME                                             0.64
=================================================================
                                *** TOTALS ***
TOTAL OUTFLOW FROM GRID SYSTEM                         0.58
TOTAL VOLUME OF OUTFLOW AND STORAGE                    4.37

  SURFACE AREA OF INUNDATION REGARDLESS OF THE TIME OF OCCURRENCE:
(FOR FLOW DEPTHS GREATER THAN THE "TOL" VALUE TYPICALLY 0.1 FT OR 0.03 M)

THE MAXIMUM INUNDATED AREA IS:                           18.23 ACRES
=================================================================
     COMPUTER RUN TIME IS:  3.25830 HRS
     THIS OUTPUT FILE WAS TERMINATED ON:  10/26/2015 AT:  19:26:30
```

Abbreviated SWMM.rpt

```
EPA STORM WATER MANAGEMENT MODEL - VERSION 5.0 (Build 5.0.022)
--------------------------------------------------------------
Element Count
*************
Number of nodes ........... 6
Number of links ........... 5

Control Actions Taken
**************************        Volume          Depth
Runoff Quantity Continuity     acre-feet         inches
Total Precipitation ......         0.000          0.000
Evaporation Loss .........         0.000          0.000
Infiltration Loss ........         0.000          0.000
Surface Runoff ...........         0.000          0.000
Final Surface Storage ....         0.000          0.000
Continuity Error (%) .....         0.000

**************************        Volume         Volume
Flow Routing Continuity        acre-feet       10^6 gal
Dry Weather Inflow .......         0.000          0.000
Wet Weather Inflow .......         0.644          0.210
Groundwater Inflow .......         0.000          0.000
RDII Inflow ..............         0.000          0.000
External Inflow ..........         0.000          0.000
External Outflow .........         0.636          0.207
Internal Outflow .........         0.000          0.000
Storage Losses ...........         0.000          0.000
Initial Stored Volume ....         0.000          0.000
Final Stored Volume ......         0.002          0.001
Continuity Error (%) .....         0.803

Outfall Loading Summary
***********************
                      Flow       Avg.       Max.       Total
                      Freq.      Flow       Flow      Volume
Outfall Node          Pcnt.       CFS        CFS    10^6 gal
I388                  88.67      0.72       4.70       0.207
-----------------------------------------------------------
System                88.67      0.72       4.70       0.207

Analysis begun on:  Mon Oct 26 16:10:43 2015
Analysis ended on:  Mon Oct 26 19:26:12 2015
Total elapsed time: 03:15:29
```

The following statements explain how and where the values in the tables were obtained from the FLO-2D modeling output files:

Under "Sum of volumes", the volume is defined (in acre feet) as:
[Infiltration & interception] + [Floodplain storage] + [TOL storage] + [Floodplain outflow] + [Stormdrain]. This value should match the rainfall volume. Any difference within 0.01ac-ft may be due to rounding error.

Under "Target volume capture", the volume is defined (in acre feet) as:
[# of bio retention grids (2436)] * [grid area (4 ft*4 ft=16ft²)] * [Effective storage depth (1 ft from 0.5 ft of elevation below curb and 0.5 ft infiltration)].

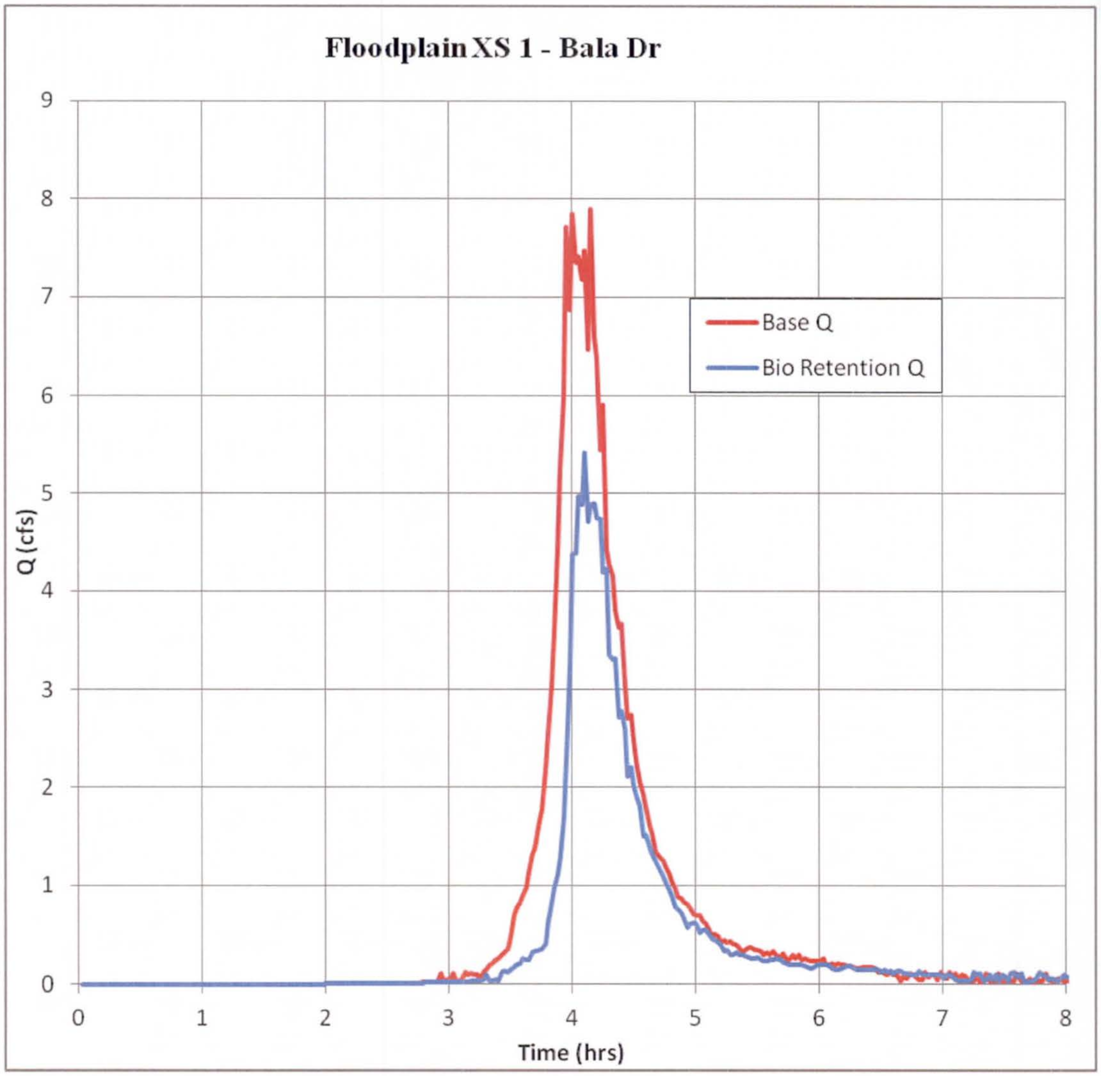
Under "Volume captured", the volume is defined (in acre feet) as:
[Bio retention Infiltration & interception] – [Base Infiltration & interception] + [Bio retention Floodplain storage] – [Base Floodplain storage]

Under "Utilization of Bio retention volume", the utilization is defined (in %) as:
[Volume captured] / [Target volume capture]

The modeling results in Table 4.2a show that if bio retention LID control is constructed in the front yards within the Focus Area with a total capacity of about 20.4% of the rainfall volume (0.89/4.37 = 20.4%) using FPLAIN.DAT and INFIL.DAT parameter adjustment both the surface outflow and the stormdrain outflow were reduced significantly. Of a potential 0.89 ac-ft capacity, the LID control captures 0.75 ac –ft (0.36 ac-ft stored in the open basin and 0.39 ac-ft infiltrated into the bottom). The average infiltration depth is about 5.23 in. out of possible 6.0 in. The utilization of the bio retention LID control capacity is 84.3%. There are multiple reasons why the utilization value is not 100%: flow does not automatically route to the bio retention grids and this model used grid elevation adjustments to connect the street to collect flow onto the bio retention grids to approximate real design conditions. The effectiveness of the bio retention LID control on flood mitigation is also presented by a floodplain maximum depth difference raster with and without LID applications and is shown in Exhibit B1.

The peak flow and volume values for the cross sections are documented in Table 4.2b below and a typical floodplain cross section hydrograph is plotted below as well. Table 4.2b shows that both the total surface peak flow and volume reduction with bio retention is about 39%. All of the floodplain hydrographs are included in Appendix C1.

Table 4.2b - Floodplain Cross Section Results								
	Base Model		Bio Retention		Reduction			
XS	Qp	Vol	Qp	Vol	Qp		Vol	
	cfs	ac-ft	cfs	ac-ft	cfs	%	ac-ft	%
1	9.21	0.45	6.03	0.29	3.18	35	0.16	36
2	0.54	0.03	0.33	0.01	0.21	39	0.02	67
3	2.42	0.10	2.38	0.10	0.04	2	0.00	0
4	6.95	0.46	2.47	0.21	4.48	65	0.25	54
5	1.28	0.04	1.26	0.04	0.02	2	0.00	0
6	5.24	0.65	1.94	0.28	3.30	63	0.37	57
7	2.84	0.37	1.49	0.24	1.35	48	0.13	35
8	8.98	0.42	5.51	0.26	3.47	39	0.16	38
9	1.78	0.05	1.10	0.04	0.68	38	0.01	20
10	0.84	0.05	1.10	0.05	-0.26	-31	0.00	0
11	1.91	0.20	1.83	0.20	0.08	4	0.00	0
Total	41.99	2.82	25.44	1.72	16.55	39	1.10	39


Floodplain XS 1 - Bala Dr
Base Q
Bio Retention Q
Q (cfs)
Time (hrs)
0
1
2
3
4
5
6
7
8
9

4.3 FLO-2D Modeling Procedures for Bio Swale

In addition to grid elevation adjustments for the grids within the Bio Swale areas, spatially varied infiltration rates and limiting soil depths method was applied by the FLO-2D model to evaluate the impact of Bio Swale on the study area hydrology and hydraulics. The detailed steps are:

Step 1: Determining Parcel Design Capacities for LID Controls

In general, total LID design capacities for all the parcels within the modeling area should be estimated based on land uses and sizes according to land use zoning and the City's on-site retention requirements, such as 100-year, 2-hour on-site retention requirement. For the Bio Swale LID control, the parcel specific Bio Swale application areas were developed based land uses and topographic features within the modeling areas as shown in Exhibit B2. The total number of grids within Bio Swale area is 1038 with total storage capacity of 0.31 ac-ft.

Step 2: Developing FLO-2D Input Data files

The steps for revising the FLO-2D input data files are as follows starting with a working base model:

1) Grid Assignment

   a) Bio swale grids – Grids were placed in areas that were already collecting flow. In this model, portions of the streets where access and parking were not critical were used to model 4 grid-wide bio swales. Grids along the lowest part of the curb were assigned as the bio swale thalweg grids while the rest of them were just assigned as bio swale grids.

2) Input Data

   a) FPLAIN.DAT
      i) Elevations – The thalweg grids were given a uniform adjustment of -0.5 ft and the bio swale grids were given a uniform adjustment of -0.25 ft. Positive slope already existed throughout the selected grids and was maintained through the adjustment.
      ii) N values – All modified grids were given an n-value of 0.075 to conservatively estimate added vegetation and rock added to the swale.

   b) INFIL.DAT – The bio retention area grid infiltration parameters were modified as if they were a loamy sand soil amendment with an additional 6 in of infiltration-loss capacity:

      i) HYDC – The hydraulic conductivity, in inches/hr: A value of 1.2 was used based on the 1995 FCDMC Drainage Design Manual, Table 4.2
      ii) SOILS – The soil suction head, in inches: a value of 2.4 was used based on the 1995 FCDMC Drainage Design Manual, Table 4.2
      iii) DTHETA – The volumetric soil moisture deficit, a coefficient that determines available volume within a depth of soil: a value of 0.3 was used based on the 1995 FCDMC Drainage Design Manual Figure 4.3.
      iv) ABSTRINF - The initial abstraction in inches: a value of 0 was used for the bio swale area grids.

v) RTIMP – A coefficient representing the imperviousness of the surface: a value of 0 was used to allow full infiltration.
vi) SOILD – The limiting soil depth in feet: A value of 1.667 was added on top of the original limiting soil depth used. This was determined by using our design depth of 6 in divided by DTHETA and converted to feet.

Step 3: Running FLO-2D Models and Documenting Results
A base model was developed without any LID applications (100-year, 6-hour storm model) and a model with Bio Swale LID control for all parcels was developed to simulate the effects of LID applications. The modeling results were documented in Table 4.3a.

The total LID design volume is the LID system capacity within the modeling area. The surface flow comparison values were from "SUMMARY.OUT" file and the storm drain flow comparison values were from SWMM.RPT file as shown in Table 4.3a and the numbers used were highlighted (These files were also included in Appendix C2):

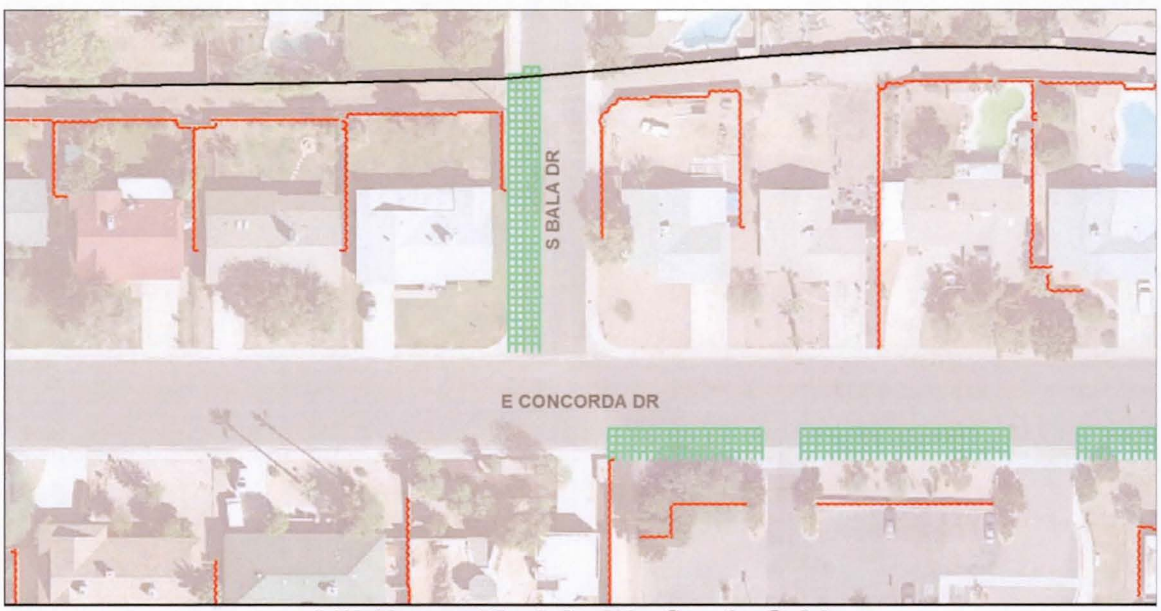
Table 4.3a Bio Swale Modeling		Model	LID 2.1	LID 13
			Base	Bio Swale
SWMM RPT	Outflow (Outfall node I338)	Qp (cfs)	8.58	8.45
	Wet weather inflow	V (acft)	1.19	1.11
	Return flow	V (acft)	0.04	0.03
SUMMARY OUT	Rainfall Volume	V (acft)	4.37	4.37
	Infiltration & interception	V (acft)	0.93	0.99
		%	21	23
	Floodplain storage	V (acft)	1.47	1.5
		%	34	34
	TOL storage	V (acft)	0.07	0.07
		%	2	2
	Floodplain outflow	V (acft)	0.76	0.79
		%	17	18
	Stormdrain (FLO-2D to SWMM)	V (acft)	1.23	1.1
		%	28	25
	Return flow (SWMM to FLO-2D)	V (acft)	0.03	0.02
Check	Sum of volumes	V (acft)	4.36	4.36
	Volume captured	V (acft)	-	0.09
	Target volume capture	V (acft)	-	0.31
	Utilization of Bioswale volume	%	-	29.1
	Street swale grids	1038		
	Elevation difference volume	0.119	acft	
	Infiltration depth added	0.5	ft	
	Infiltration volume	0.191	acft	
	Total volume capacity	0.310	acft	

LID Focus Model - Bio Swale Grids

Model Boundary — Walls — Bio Swale

N

1 inch = 400 feet



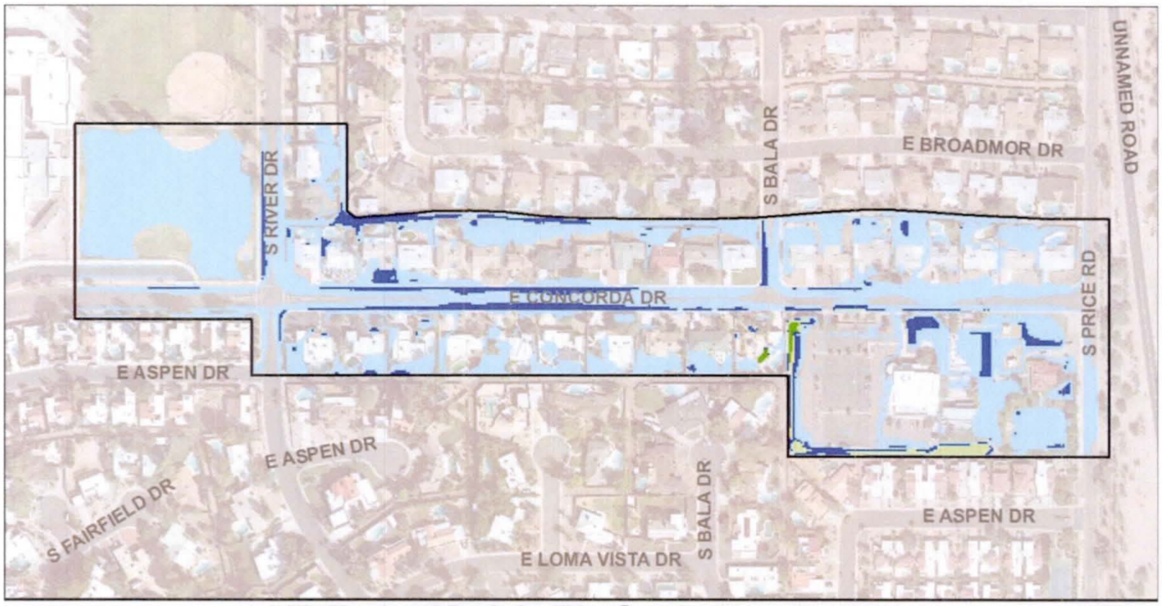
LID Focus Model - Bio Swale Grids

Model Boundary — Walls — Bio Swale

N

1 inch = 100 feet

The maximum flow depth for the focus area and a close-up area are shown below.



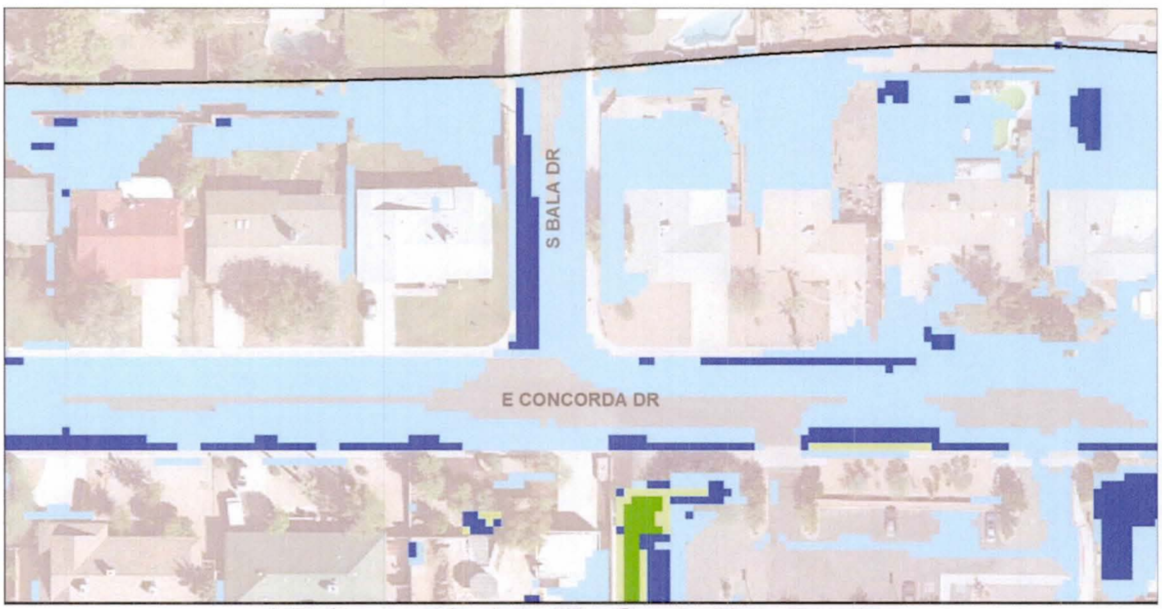
LID Focus Model - Bio Swale Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 400 fe



LID Focus Model - Bio Swale Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 100 fe

Abbreviated SUMMARY.OUT FILE

```
                 Pro Model - Build No. 15.02.10
================================================================
                     MASS BALANCE   INFLOW - OUTFLOW VOLUME
================================================================
                           *** INFLOW (ACRE-FEET) ***
TOTAL POINT RAINFALL:                                  2.5200 INCHES
                                                    WATER
RAINFALL VOLUME                                        4.37
SURFACE WATER INFLOW HYDROGRAPH                      0.00
                                                   ---------
INFLOW HYDROGRAPHS + RAINFALL                          4.37
===============================================================
                           *** SURFACE OUTFLOW (ACRE-FT) ***
OVERLAND INFILTRATED AND INTERCEPTED WATER         0.90 INCHES
          OVERLAND FLOW                             WATER
WATER LOST TO INFILTRATION & INTERCEPTION              0.99
FLOODPLAIN STORAGE                                     1.50
OVERLAND STORAGE DUE TO TOL                            0.07
FLOODPLAIN OUTFLOW HYDROGRAPH                          0.79
                                                   ---------
FLOODPLAIN OUTFLOW, INFILTRATION & STORAGE             3.28
TOTAL SURFACE OUTFLOW AND STORAGE                      2.29
===============================================================
          *** FLO-2D STORM DRAIN EXCHANGE VOLUME (ACRE-FT) ***
FLO-2D TO SWMM THROUGH INLETS                          1.10
SWMM TO FLO-2D FROM RETURNING FLOW                     0.02
SWMM TO FLO-2D FROM OUTFALL                            0.00
FLO-2D TO SWMM FROM OUTFALL                            0.00
                                                   ---------
NET VOLUME                                             1.08
================================================================
                                 *** TOTALS ***
TOTAL OUTFLOW FROM GRID SYSTEM                         0.79
TOTAL VOLUME OF OUTFLOW AND STORAGE                    4.37

  SURFACE AREA OF INUNDATION REGARDLESS OF THE TIME OF OCCURRENCE:
(FOR FLOW DEPTHS GREATER THAN THE "TOL" VALUE TYPICALLY 0.1 FT OR 0.03 M)
THE MAXIMUM INUNDATED AREA IS:                           18.23 ACRES
================================================================
     COMPUTER RUN TIME IS:  3.57471 HRS
     THIS OUTPUT FILE WAS TERMINATED ON:  10/23/2015  AT:  20:28:18
```

Abbreviated SWMM.rpt

```
EPA STORM WATER MANAGEMENT MODEL - VERSION 5.0 (Build 5.0.022)
--------------------------------------------------------------
Element Count
*************
Number of nodes ........... 6
Number of links ........... 5

Control Actions Taken
*************************         Volume          Depth
Runoff Quantity Continuity      acre-feet        inches
Total Precipitation ......          0.000         0.000
Evaporation Loss .........          0.000         0.000
Infiltration Loss ........          0.000         0.000
Surface Runoff ...........          0.000         0.000
Final Surface Storage ....          0.000         0.000
Continuity Error (%) .....          0.000

*************************         Volume         Volume
Flow Routing Continuity         acre-feet      10^6 gal
Dry Weather Inflow .......          0.000         0.000
Wet Weather Inflow .......          0.644         0.210
Groundwater Inflow .......          0.000         0.000
RDII Inflow ..............          0.000         0.000
External Inflow ..........          0.000         0.000
External Outflow .........          0.636         0.207
Internal Outflow .........          0.000         0.000
Storage Losses ...........          0.000         0.000
Initial Stored Volume ....          0.000         0.000
Final Stored Volume ......          0.002         0.001
Continuity Error (%) .....          0.803

Outfall Loading Summary
***********************
                      Flow       Avg.       Max.       Total
                      Freq.      Flow       Flow      Volume
Outfall Node          Pcnt.       CFS        CFS    10^6 gal
I388                  88.67      0.72       4.70       0.207
-----------------------------------------------------------
System                88.67      0.72       4.70       0.207

Analysis begun on:  Mon Oct 26 16:10:43 2015
Analysis ended on:  Mon Oct 26 19:26:12 2015
Total elapsed time: 03:15:29
```

Under "Sum of volumes", the volume is defined (in acre feet) as:
[Infiltration & interception] + [Floodplain storage] + [TOL storage] + [Floodplain outflow] + [Stormdrain]. This value should match the rainfall volume. Any difference within 0.01ac-ft may be due to rounding error.

Under "Target volume capture", the volume is defined (in acre feet) as:
[# of bio swale grids(1038)] * [grid area (4 ft*4 ft=16ft^2)] * [Effective storage depth (0.5 ft or 0.25 ft depending on location in bio swale and 0.5 ft infiltration)].

Under "Volume captured", the volume is defined (in acre feet) as:
[Bio swale Infiltration & interception] – [Base Infiltration & interception] + [Bio swale Floodplain storage] – [Base Floodplain storage]

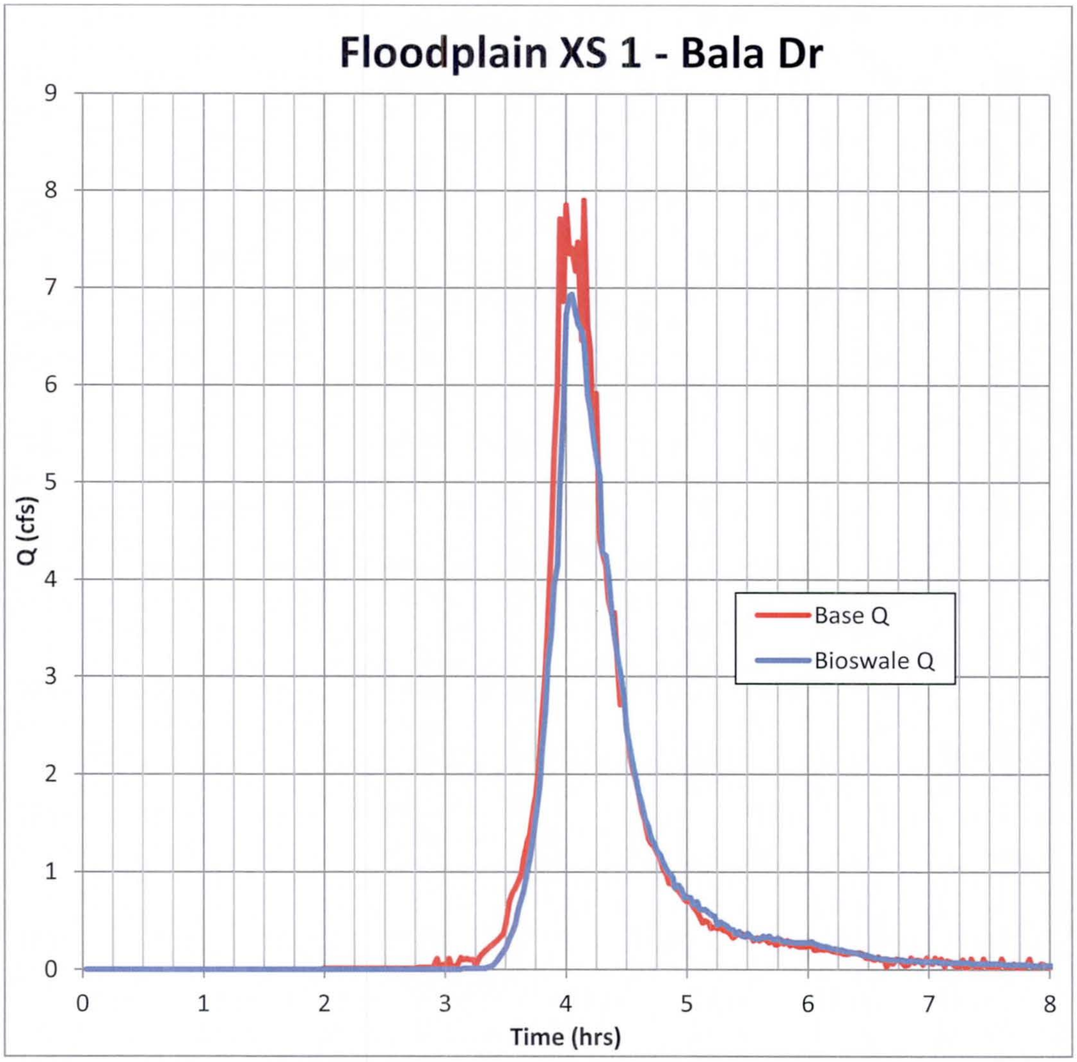
Under "Utilization of Bio swale volume", the utilization is defined (in %) as:
[Volume captured] / [Target volume capture]

The modeling results in Table 4.3a show that modeling small bio swales within the small grid model (total capacity is about 7.1% of the rainfall volume) using FPLAIN.DAT and INFIL.DAT parameter adjustment as outlined in this memo increases the volume infiltrated, stored on the floodplain, as well as the stormdrain outflow. Of a potential 0.31 ac-ft, the model captures 0.09 ac –ft. This value is lower than expected because the grids are already located in areas that collect and convey flow, so not much remains in its storage. A floodplain maximum depth difference raster is shown in Exhibit B2.

The peak flow and volume values for the cross sections are documented in Table 4.3b below and a typical floodplain cross section hydrograph is plotted below as well. Table 4.3b showed that the total surface peak flow reduction with bio swale is about 15% and that the total volume reduction is about 5%. All of the floodplain hydrographs are included in Appendix C2.

Table 4.3b Floodplain Cross Section Results

	Base Model		Bio Swale		Reduction			
XS	Qp	Vol	Qp	Vol	Qp		Vol	
	cfs	ac-ft	cfs	ac-ft	cfs	%	ac-ft	%
1	9.21	0.45	7.37	0.41	1.84	20	0.04	9
2	0.54	0.03	0.83	0.11	-0.29	-54	-0.08	-267
3	2.42	0.10	2.28	0.10	0.14	6	0.00	0
4	6.95	0.46	6.20	0.45	0.75	11	0.01	2
5	1.28	0.04	1.30	0.04	-0.02	-2	0.00	0
6	5.24	0.65	4.94	0.64	0.30	6	0.01	2
7	2.84	0.37	2.13	0.29	0.71	25	0.08	22
8	8.98	0.42	7.27	0.37	1.71	19	0.05	12
9	1.78	0.05	0.76	0.03	1.02	57	0.02	40
10	0.84	0.05	0.83	0.05	0.01	1	0.00	0
11	1.91	0.20	2.01	0.20	-0.10	-5	0.00	0
Total	41.99	2.82	35.92	2.69	6.07	15	0.13	5


Floodplain XS 1 - Bala Dr
Q (cfs)
Time (hrs)
Base Q
Bioswale Q
0
1
2
3
4
5
6
7
8
9

4.4 FLO-2D Modeling Procedures for Pervious Pavement

Spatially varied infiltration rates and limiting soil depths method was applied by the FLO-2D model to evaluate the impact of pervious pavement on the study area hydrology and hydraulics. The detailed steps are:

Step 1: Determining Parcel Design Capacities for LID Controls

In general, total LID design capacities for all the parcels within the modeling area should be estimated based on land uses and sizes according to land use zoning and the City's on-site retention requirements, such as 100-year, 2-hour on-site retention requirement. For the Pervious Pavement LID control, the parcel specific Pervious Pavement application areas were developed based driveways and parking lots within the modeling areas as shown in Exhibit B3. The total number of grids within pervious pavement area is 5802 with 4.8 in storage capacity. The capacity is based on a typical depth of 12 in for parking lots and residential uses, with a porosity of 0.4. These values were obtained from a Belgard Commercial memo (page 14) on Sustainable & Pervious Pavement Systems which was included in Appendix A3. Generally, the surface of the pervious pavement will limit the infiltration rate. Pavers with a typical void opening of 5% will limit the infiltration to 50-75 in/hr. Porous concretes can generally infiltrate 100-400 in/hr. An infiltration rate of 500in/hr was used in order to remove it as a limitation on the potential for the volume capture under the direction of the FCDMC.

Step 2: Developing INFIL.DAT files

The steps for revising the INFIL.DAT file are as follows starting with a working base model:

1) Grid assignment for pervious pavement - In our model, grids overlaying driveways and parking lots were assigned as pervious pavement grids. This was performed in GIS using the MGRID shapefile that can be exported from FLO-2D GDS/Mapper.

2) Parameters for INFIL.DAT – modifying the spatial parameters for pervious pavement grids:
   a) HYDC – The hydraulic conductivity in inches/hr: a value of 500 was used;
   b) SOILS – The soil suction head in inches: a value of 1 was used based on the 1995 FCDMC Drainage Design Manual Figure 4.3;
   c) DTHETA – The volumetric soil moisture deficit, a coefficient that determines available volume within a depth of soil: a value of 0.3 was used based on the 1995 FCDMC Drainage Design Manual Figure 4.3;
   d) ABSTRINF – The initial abstraction in inches: a value of 0 was used for the pervious pavement.
   e) RTIMP – A coefficient representing the imperviousness of the surface: a value of 0 was used to allow full infiltration;
   f) SOILD – The limiting soil depth in feet: A value of 1.333 was used. This was determined by using our design depth of 4.8 in divided by DTHETA and converted to feet.

3) Collection of runoff
   Modifying infiltration parameters on grids to model LID features will not guarantee that their effects will be reflected in the results. If the effective storage capacity of the pervious pavement is greater than the rainfall depth, steps need to be taken to collect flow to the LID areas to measure the full effect. There are multiple ways to

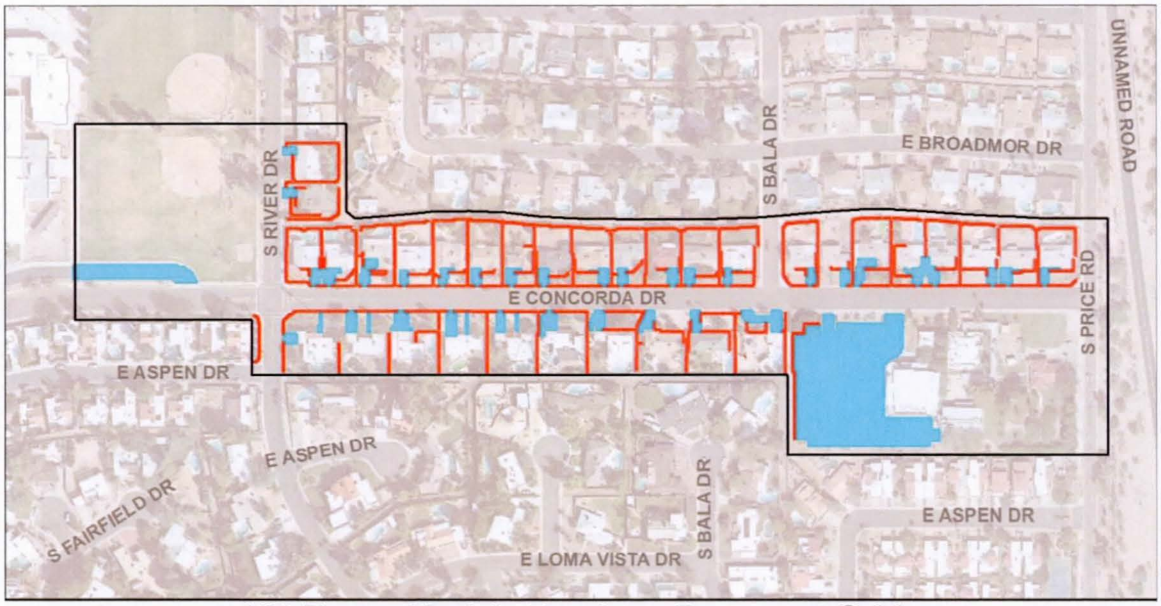
modify the input files in FLO-2D to route the flow (Exhibit B3 shows the pervious pavement modeling area with artificial walls):

a) Walls as modeled in LEVEE.DAT – This can be used to restrict where water flows and can be used to force water to flow towards feature grids. This method is the easiest to implement on a larger scale and is not recommended when looking at one particular parcel. This was used for all residential parcels within the LID Focus Area model due to its ease of implementation;
b) Hydraulic structures using HYSTRUC.DAT –This can be used to transfer water that is ponding or flowing over a particularly low spot on a parcel to the feature (Pervious Pavement) grids. This method can also be used to model a French drain or used in conjunction with walls to most realistically simulate a roof gutter and downspout.
c) Manipulation of elevation data in FPLAIN.DAT: This method is the most realistic but requires more effort. It is ideal as it will most realistically mimic any grading involved. This was done for the church site on the southeast corner of the model in order to inundate the large parking lot.

Step 3: Running FLO-2D Models and Documenting Results

A base model was developed without any LID applications (100-year, 6-hour storm model) and a model with pervious pavement LID control for all parcels was developed to simulate the effects of LID applications. The modeling results were documented in Table 4.4a. A floodplain maximum depth difference raster is shown in Exhibit B3.

The total LID design volume is the LID system capacity within the modeling area. The surface flow comparison values were from "SUMMARY.OUT" file and the storm drain flow comparison values were from SWMM.RPT file as shown in Table 4.4a and the numbers used were highlighted (These files were also included in Appendix C3):



LID Focus Model - Pervious Pavement Grids

Model Boundary | Walls for P. Pavement | Pervious Pavement | N

1 inch = 400 feet

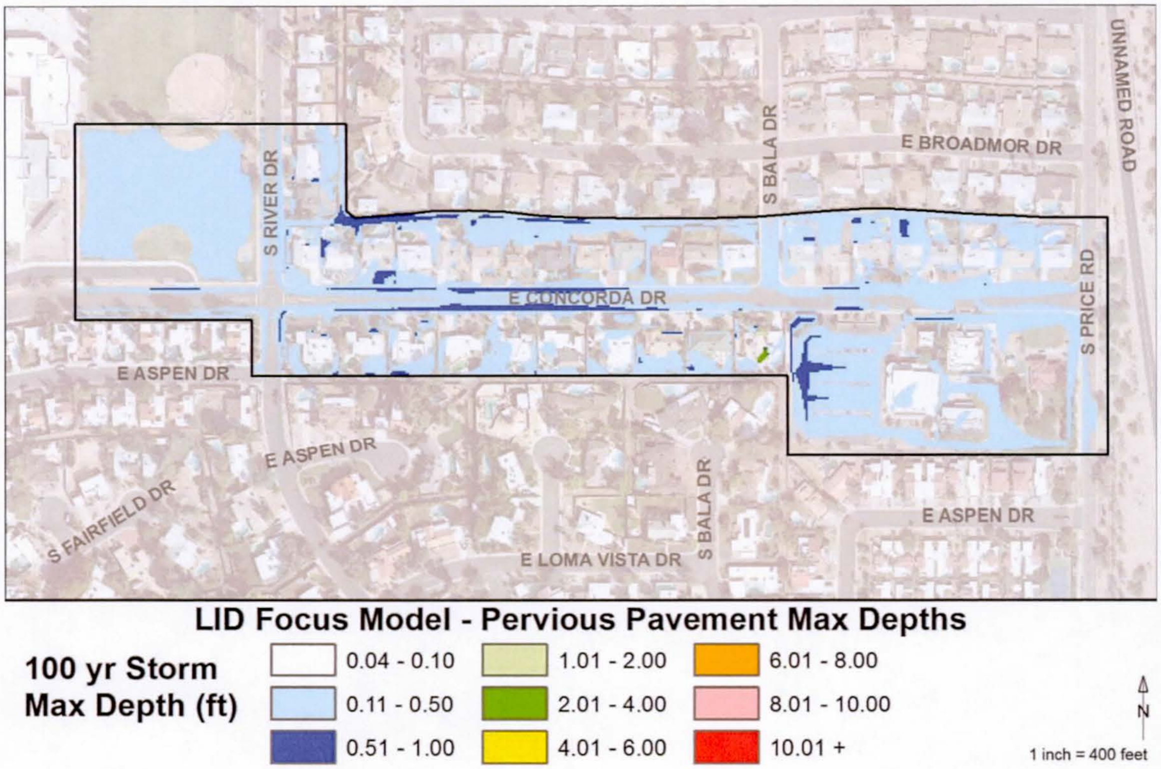
LID Focus Model - Pervious Pavement Grids

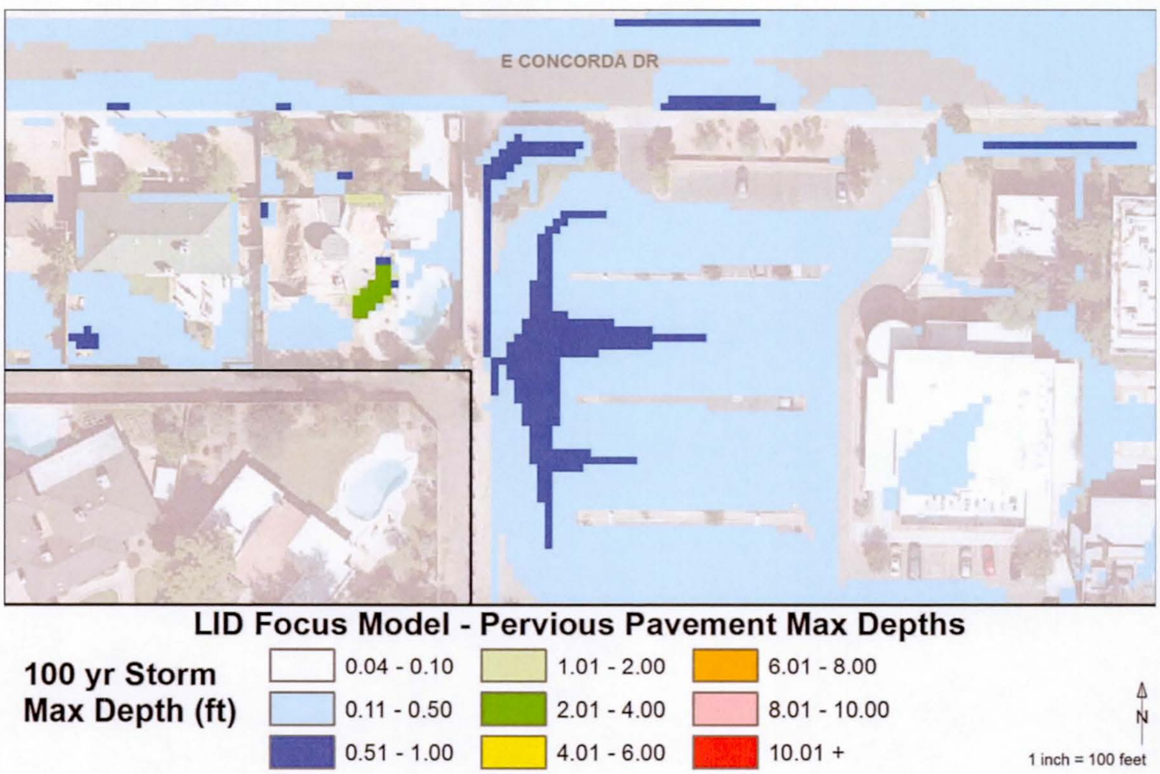
Model Boundary | Walls for P. Pavement | Pervious Pavement | N

1 inch = 100 feet

	Table 4.4a Pervious Pavement Modeling	Model	LID 2.1	LID 7.3
			Base	P. Pavement
SWMM RPT	Outflow (Outfall node I338)	Qp (cfs)	8.58	7.52
	Wet weather inflow	V (acft)	1.19	1.02
	Return flow	V (acft)	0.04	0.02
SUMMARY OUT	Rainfall Volume	V (acft)	4.37	4.37
	Infiltration & interception	V (acft)	0.93	1.67
		%	21	38
	Floodplain storage	V (acft)	1.47	1.09
		%	34	25
	TOL storage	V (acft)	0.07	0.07
		%	2	2
	Floodplain outflow	V (acft)	0.76	0.59
		%	17	14
	Stormdrain (FLO-2D to SWMM)	V (acft)	1.23	1.02
		%	28	23
	Return flow (SWMM to FLO-2D)	V (acft)	0.03	0.00
Check	Sum of volumes	V (acft)	4.36	4.37
	Volume captured	V (acft)	-	0.74
	Target volume capture	V (acft)	-	0.85
	Utilization of pervious pavement volume	%	-	86.81
	Rainfall Depth	2.52	in	
	Total Grids in Model (4'x4')	56693		
	Total Model Area	20.8	ac	
	Number of Pervious Pavement Grids (4'x4')	5802		
	Effective Pervious Pavement Depth	0.4	ft	
	Pervious Pavement Volume Capacity	0.852	acft	

The maximum flow depth for the focus area and a close-up area are shown below.


UNNAMED ROAD
E BROADMOR DR
S BALA DR
S RIVER DR
S PRICE RD
E CONCORDA DR
E ASPEN DR
E ASPEN DR
S FAIRFIELD DR
S BALA DR
E ASPEN DR
E LOMA VISTA DR
LID Focus Model - Pervious Pavement Max Depths
100 yr Storm
Max Depth (ft)
0.04 - 0.10
0.11 - 0.50
0.51 - 1.00
1.01 - 2.00
2.01 - 4.00
4.01 - 6.00
6.01 - 8.00
8.01 - 10.00
10.01 +
N
1 inch = 400 feet


E CONCORDA DR
LID Focus Model - Pervious Pavement Max Depths
100 yr Storm
Max Depth (ft)
0.04 - 0.10
0.11 - 0.50
0.51 - 1.00
1.01 - 2.00
2.01 - 4.00
4.01 - 6.00
6.01 - 8.00
8.01 - 10.00
10.01 +
N
1 inch = 100 feet

```
                  Abbreviated SUMMARY.OUT FILE

              Pro Model - Build No. 15.02.10
=====================================================================
                MASS BALANCE   INFLOW - OUTFLOW VOLUME
=====================================================================
                           *** INFLOW (ACRE-FEET) ***
TOTAL POINT RAINFALL:                                  2.5200 INCHES

                                                   WATER
RAINFALL VOLUME                                      4.37
SURFACE WATER INFLOW HYDROGRAPH                    0.00
                                                 ---------
INFLOW HYDROGRAPHS + RAINFALL                        4.37
=====================================================================
                           *** SURFACE OUTFLOW (ACRE-FT) ***

OVERLAND INFILTRATED AND INTERCEPTED WATER       1.28 INCHES

          OVERLAND FLOW                            WATER
WATER LOST TO INFILTRATION & INTERCEPTION            1.67
FLOODPLAIN STORAGE                                   1.09
OVERLAND STORAGE DUE TO TOL                          0.07
FLOODPLAIN OUTFLOW HYDROGRAPH                        0.59
                                                 ---------
FLOODPLAIN OUTFLOW, INFILTRATION & STORAGE           3.35

TOTAL SURFACE OUTFLOW AND STORAGE                    1.68
=====================================================================
          *** FLO-2D STORM DRAIN EXCHANGE VOLUME (ACRE-FT) ***

FLO-2D TO SWMM THROUGH INLETS                        1.02
SWMM TO FLO-2D FROM RETURNING FLOW                   0.00
SWMM TO FLO-2D FROM OUTFALL                          0.00
FLO-2D TO SWMM FROM OUTFALL                          0.00
                                                 ---------
NET VOLUME                                           1.02
=====================================================================
                                 *** TOTALS ***
TOTAL OUTFLOW FROM GRID SYSTEM                       0.59
TOTAL VOLUME OF OUTFLOW AND STORAGE                  4.37

  SURFACE AREA OF INUNDATION REGARDLESS OF THE TIME OF OCCURRENCE:
(FOR FLOW DEPTHS GREATER THAN THE "TOL" VALUE TYPICALLY 0.1 FT OR 0.03 M)

THE MAXIMUM INUNDATED AREA IS:                         17.85 ACRES
=====================================================================
     COMPUTER RUN TIME IS :  3.32617 HRS
     THIS OUTPUT FILE WAS TERMINATED ON:  10/19/2015  AT:  15: 6:47
```

Abbreviated SWMM.RPT

```
EPA STORM WATER MANAGEMENT MODEL - VERSION 5.0 (Build 5.0.022)
--------------------------------------------------------------

*********************************************************
NOTE: The summary statistics displayed in this report are
based on results found at every computational time step,
not just on results from each reporting time step.
*********************************************************

**************************        Volume         Depth
Runoff Quantity Continuity     acre-feet        inches
**************************     ---------       -------
Total Precipitation ......         0.000         0.000
Evaporation Loss .........         0.000         0.000
Infiltration Loss ........         0.000         0.000
Surface Runoff ...........         0.000         0.000
Final Surface Storage ....         0.000         0.000
Continuity Error (%) .....         0.000


**************************        Volume        Volume
Flow Routing Continuity        acre-feet      10^6 gal
**************************     ---------     ---------
Dry Weather Inflow .......         0.000         0.000
Wet Weather Inflow .......         1.023         0.333
Groundwater Inflow .......         0.000         0.000
RDII Inflow ..............         0.000         0.000
External Inflow ..........         0.000         0.000
External Outflow .........         0.986         0.321
Internal Outflow .........         0.018         0.006
Storage Losses ...........         0.000         0.000
Initial Stored Volume ....         0.000         0.000
Final Stored Volume ......         0.002         0.001
Continuity Error (%) .....         1.673

***********************
Outfall Loading Summary
***********************

-----------------------------------------------------------
                     Flow       Avg.       Max.       Total
                     Freq.      Flow       Flow      Volume
Outfall Node         Pcnt.       CFS        CFS    10^6 gal
-----------------------------------------------------------
I388                 88.67      1.12       7.52       0.321
-----------------------------------------------------------
System               88.67      1.12       7.52       0.321

Analysis begun on:  Mon Oct 19 11:46:52 2015
Analysis ended on:  Mon Oct 19 15:06:28 2015
Total elapsed time: 03:19:36
```

Under "Sum of volumes", the volume is defined (in acre feet) as: [Infiltration & interception] + [Floodplain storage] + [TOL storage] + [Floodplain outflow] + [Stormdrain]. This value should match the rainfall volume. Any difference within 0.01ac-ft may be due to rounding error.

Under "Target volume capture", the volume is defined (in acre feet) as:
[# of pervious pavement grids(5802)] * [grid area (4 ft*4 ft=16ft²)] * [Effective pervious pavement storage depth (0.4 ft = 4.8 in)].

Under "Volume captured", the volume is defined (in acre feet) as:
[P.Pavement Infiltration & interception] – [Base Infiltration & interception]

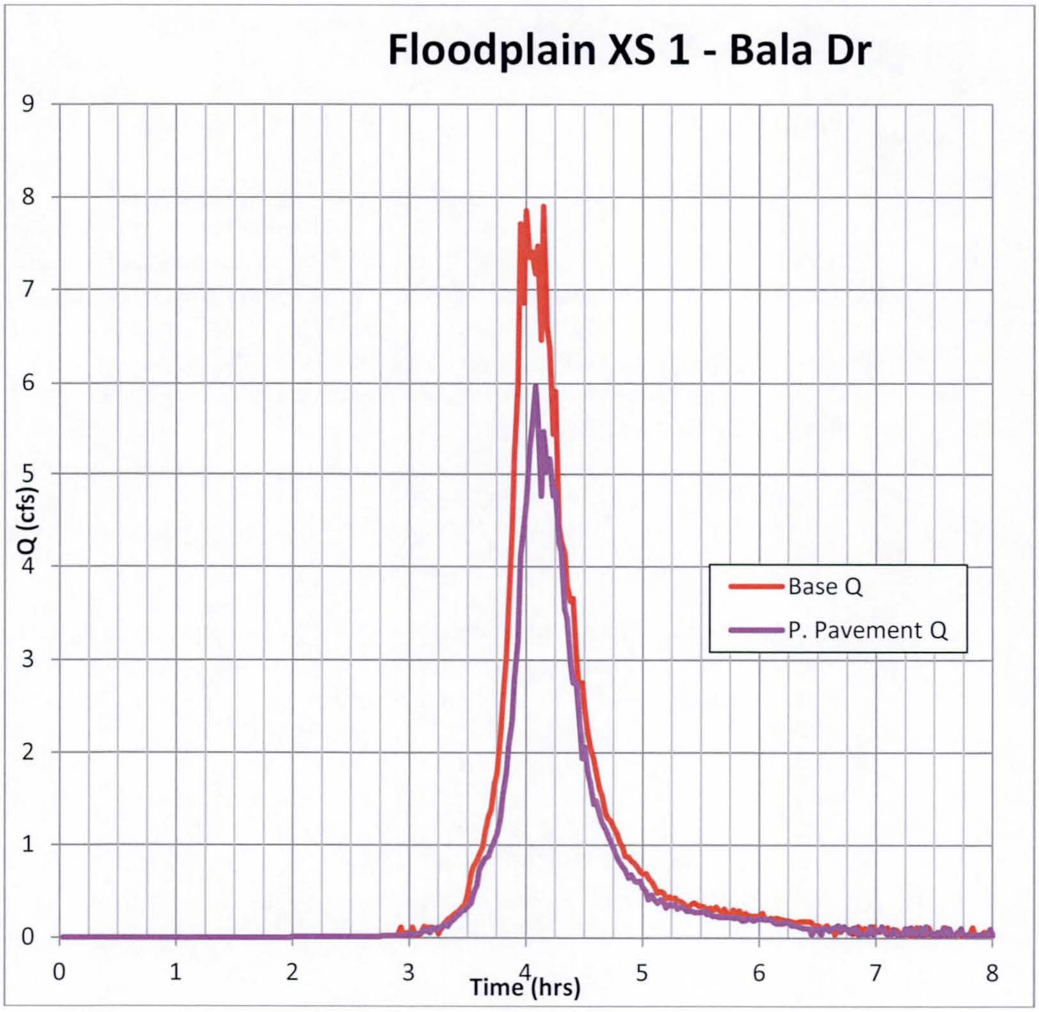
Under "Utilization of pervious pavement volume", the utilization is defined (in %) as:
[Volume captured] / [Target volume capture]

The modeling results in Table 4.4a show that modeling the driveways and parking lots within the small grid model (total capacity is about 19.5% of the rainfall volume) using INFIL.DAT parameter adjustment as outlined in this memo reduce the floodplain storage (25.8%) and outflow (22.4%), as well as the stormdrain outflow. Of a potential 0.85 ac-ft, the model infiltrates 0.74 ac –ft. There are multiple reasons why this value is not 100%. Flow does not automatically route to the pervious pavement grids. This model used artificial walls and site grading to help guide flow onto the pervious pavement grids to approximate real design conditions. These walls and the grading could be refined in iterations along with possible modifications to hydraulic structures to achieve 100%, which would be more feasible if looking at a smaller model or a single parcel.

The peak flow and volume values for the cross sections are documented in Table 4.4b below and a typical floodplain cross section hydrograph is plotted below as well. Table 4.4b shows that the total surface peak flow reduction with pervious pavement is about 29% and that the total volume reduction is about 19%. All of the floodplain hydrographs are included in Appendix C3.

Table 4.4b Floodplain Cross Section Results

	Base Model		P. Pavement Model		Reduction			
XS	Qp	Vol	Qp	Vol	Qp		Vol	
	cfs	ac-ft	cfs	ac-ft	cfs	%	ac-ft	%
1	9.21	0.45	6.45	0.33	2.76	30	0.12	27
2	0.54	0.03	0.47	0.02	0.07	13	0.01	33
3	2.42	0.10	1.66	0.07	0.76	31	0.03	30
4	6.95	0.46	5.19	0.41	1.76	25	0.05	11
5	1.28	0.04	1.20	0.04	0.08	6	0.00	0
6	5.24	0.65	3.89	0.62	1.35	26	0.03	5
7	2.84	0.37	1.94	0.26	0.90	32	0.11	30
8	8.98	0.42	5.78	0.30	3.20	36	0.12	29
9	1.78	0.05	0.70	0.02	1.08	61	0.03	60
10	0.84	0.05	0.71	0.03	0.13	16	0.02	40
11	1.91	0.20	1.78	0.18	0.13	7	0.02	10
Total	41.99	2.82	29.77	2.28	12.22	29	0.54	19


Floodplain XS 1 - Bala Dr
Q (cfs)
9
8
7
6
5
4
3
2
1
0
0
1
2
3
4
5
6
7
8
Time (hrs)
Base Q
P. Pavement Q

4.5 FLO-2D Modeling Procedures for Rainwater Harvesting

Spatially varied Initial Abstraction values, IA, were applied by the FLO-2D model to evaluate the impact of Rainwater Harvesting LID control on the study area hydrology and hydraulics. The detailed steps are:

Step 1: Determining Parcel Design Capacities for LID Controls

In general, total LID design capacities for all the parcels within the modeling area should be estimated based on land uses and sizes according to land use zoning and the City's on-site retention requirements, such as 100-year, 2-hour on-site retention requirement. For the Rainwater Harvesting LID control, the parcel specific Rainwater Harvesting application areas were developed based building roof features within the modeling areas as shown in Exhibit B4. The total number of grids within Rainwater Harvesting area is 8392 with total storage capacity of 0.12 ac-ft.

Step 2: Developing FLO-2D Input Data files

The steps for revising the FLO-2D input data files are as follows starting with a working base model:

1) Assign roof grids. In our model, grids overlaying building features as characterized in the surface feature data shapefile provided by FCDMC were assigned as roof grids and then spot checked. This was performed in GIS using the MGRID shapefile that can be exported from FLO-2D GDS/Mapper.

2) Parameters for INFIL.DAT – modifying the spatial parameters for roof grids

    a) ABSTRINF – The initial abstraction in inches: This value was modified based on 1000 gallons of volume spread across a roof area. Grids were individually attributed with the area of the building they overlaid. The depth adjustment to IA was then calculated:

[New IA(in)] = [Exist. IA(in)] + {[Grid area (ft^2)]* [1000 (gal)] * [1/7.48 (ft^3/gal)] / [Roof area (ft^2)] * [12 (in/ft)]}.

Collection of runoff:

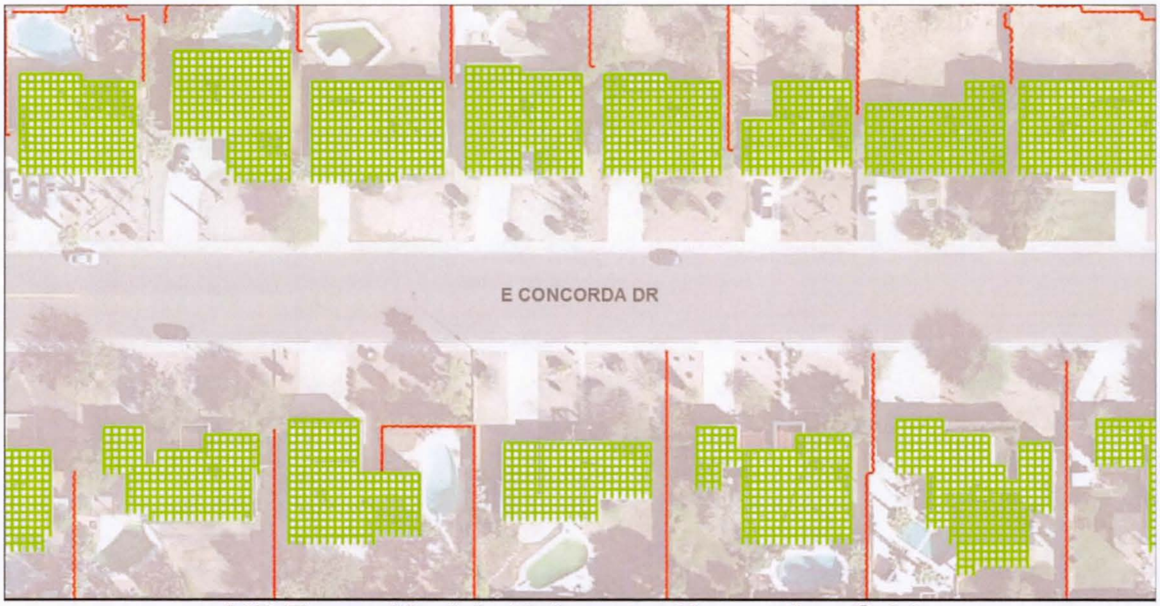
Rain tanks and cisterns generally only collect water from a roof. In this modeling scenario, only roof grids were modified, so no additional routing was necessary.

Step 3: Running FLO-2D Models and Documenting Results

A base model was developed without any LID applications (100-year, 6-hour storm model) and a model with Rainwater Harvesting LID control for all buildings (40) was developed to simulate the effects of LID applications. The modeling results were documented in Table 4.5a.

The total LID design volume is the LID system capacity within the modeling area. The surface flow comparison values were from "SUMMARY.OUT" file and the storm drain flow comparison values were from SWMM.RPT file as shown in Table 4.5a and the numbers used were highlighted (These files were also included in Appendix C4):

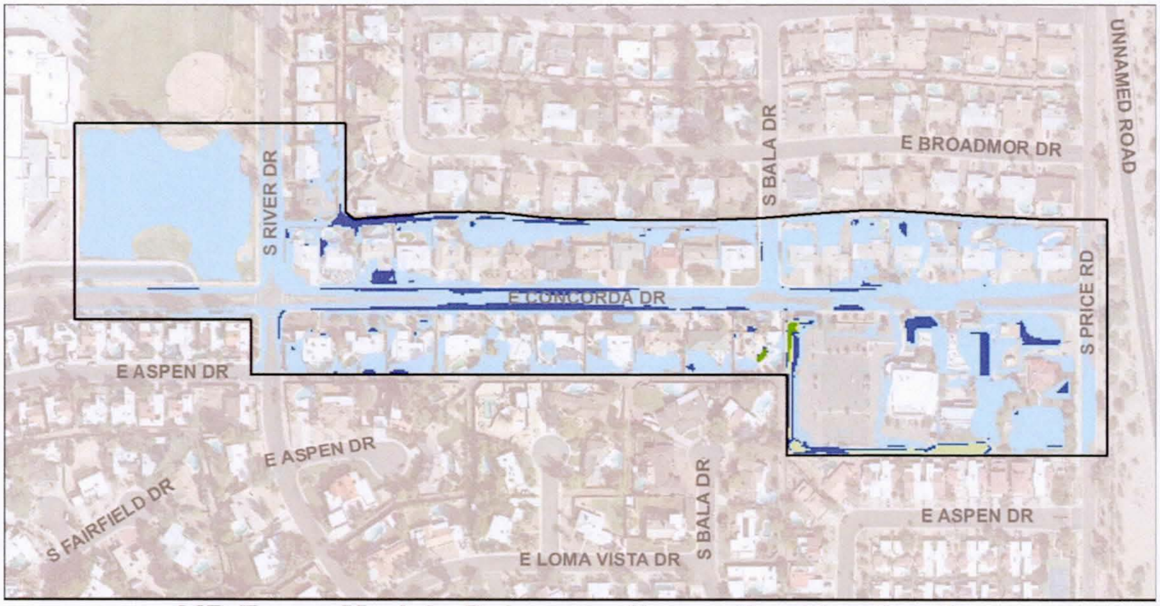
LID Focus Model - Rainwater Harvesting Grids



LID Focus Model - Rainwater Harvesting Grids

Table 4.5a Rainwater Harvesting Modeling		Model	LID 2.1	LID 9.3
			Base	Rainwater Harvesting
SWMM RPT	Outflow (Outfall node I338)	Qp (cfs)	8.58	8.62
	Wet weather inflow	V (acft)	1.19	1.15
	Return flow	V (acft)	0.04	0.04
SUMMARY OUT	Rainfall Volume	V (acft)	4.37	4.37
	Infiltration & interception	V (acft)	0.93	1.05
		%	*21*	*24*
	Floodplain storage	V (acft)	1.47	1.44
		%	*34*	*33*
	TOL storage	V (acft)	0.07	0.07
		%	*2*	*2*
	Floodplain outflow	V (acft)	0.76	0.73
		%	*17*	*17*
	Stormdrain (FLO-2D to SWMM)	V (acft)	1.23	1.17
		%	*28*	*27*
	Return flow (SWMM to FLO-2D)	V (acft)	0.03	0.02
Check	Sum of volumes	V (acft)	4.36	4.37
	Volume captured	V (acft)	-	0.12
	Target volume capture	V (acft)	-	0.12
	Utilization of Rain Tank volume	%	-	97.7
	Roof grids	8392		
	Roof Area	3.08	ac	
	Roofs	40		
	Σ1000-gal tanks volume	0.123	acft	

The maximum flow depth for the focus area and a close-up area are shown below.



LID Focus Model - Rainwater Harvesting Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 400 feet

LID Focus Model - Rainwater Harvesting Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 100 feet

```
                    Abbreviated SUMMARY.OUT FILE
                 Pro Model - Build No. 15.02.10

                         *** INFLOW (ACRE-FEET) ***
TOTAL POINT RAINFALL:                                  2.5200 INCHES
                                                    WATER
RAINFALL VOLUME                                        4.37
SURFACE WATER INFLOW HYDROGRAPH                      0.00
                                                   ---------
INFLOW HYDROGRAPHS + RAINFALL                          4.37
======================================================================
                         *** SURFACE OUTFLOW (ACRE-FT) ***
OVERLAND INFILTRATED AND INTERCEPTED WATER         0.95 INCHES
          OVERLAND FLOW                             WATER
WATER LOST TO INFILTRATION & INTERCEPTION              1.05
FLOODPLAIN STORAGE                                     1.44
OVERLAND STORAGE DUE TO TOL                            0.07
FLOODPLAIN OUTFLOW HYDROGRAPH                          0.73
                                                   ---------
FLOODPLAIN OUTFLOW, INFILTRATION & STORAGE             3.22
TOTAL SURFACE OUTFLOW AND STORAGE                      2.17
======================================================================
          *** FLO-2D STORM DRAIN EXCHANGE VOLUME (ACRE-FT) ***
FLO-2D TO SWMM THROUGH INLETS                          1.17
SWMM TO FLO-2D FROM RETURNING FLOW                     0.02
SWMM TO FLO-2D FROM OUTFALL                            0.00
FLO-2D TO SWMM FROM OUTFALL                            0.00
                                                   ---------
NET VOLUME                                             1.15
======================================================================
                               *** TOTALS ***
TOTAL OUTFLOW FROM GRID SYSTEM                         0.73
TOTAL VOLUME OF OUTFLOW AND STORAGE                    4.37

  SURFACE AREA OF INUNDATION REGARDLESS OF THE TIME OF OCCURRENCE:
(FOR FLOW DEPTHS GREATER THAN THE "TOL" VALUE TYPICALLY 0.1 FT OR 0.03 M)

THE MAXIMUM INUNDATED AREA IS:                           18.23 ACRES
======================================================================
     COMPUTER RUN TIME IS:  3.83838 HRS
     THIS OUTPUT FILE WAS TERMINATED ON:  10/15/2015  AT:  18:55:35
```

Abbreviated SWMM.rpt

```
EPA STORM WATER MANAGEMENT MODEL - VERSION 5.0 (Build 5.0.022)
--------------------------------------------------------------
Element Count
*************
Number of nodes ........... 6
Number of links ........... 5

Control Actions Taken
**************************        Volume         Depth
Runoff Quantity Continuity      acre-feet        inches
Total Precipitation ......          0.000         0.000
Evaporation Loss .........          0.000         0.000
Infiltration Loss ........          0.000         0.000
Surface Runoff ...........          0.000         0.000
Final Surface Storage ....          0.000         0.000
Continuity Error (%) .....          0.000

**************************        Volume        Volume
Flow Routing Continuity         acre-feet      10^6 gal
Dry Weather Inflow .......          0.000         0.000
Wet Weather Inflow .......          1.152         0.376
Groundwater Inflow .......          0.000         0.000
RDII Inflow ..............          0.000         0.000
External Inflow ..........          0.000         0.000
External Outflow .........          1.109         0.362
Internal Outflow .........          0.035         0.011
Storage Losses ...........          0.000         0.000
Initial Stored Volume ....          0.000         0.000
Final Stored Volume ......          0.002         0.001
Continuity Error (%) .....          0.534

Outfall Loading Summary
***********************
                      Flow       Avg.       Max.       Total
                      Freq.      Flow       Flow      Volume
Outfall Node          Pcnt.       CFS        CFS    10^6 gal
I388                  88.67      1.26       8.62       0.361
-----------------------------------------------------------
System                88.67      1.26       8.62       0.361

Analysis begun on:  Thu Oct 15 15:04:57 2015
Analysis ended on:  Thu Oct 15 18:55:16 2015
Total elapsed time: 03:50:19
```

Under "Sum of volumes", the volume is defined (in acre feet) as:
[Infiltration & interception] + [Floodplain storage] + [TOL storage] + [Floodplain outflow] + [Stormdrain]. This value should match the rainfall volume. Any difference within 0.01ac-ft may be due to rounding error.

Under "Target volume capture", the volume is defined (in acre feet) as:
[# of roof grids(8392)] * [grid area (4 ft*4 ft=16ft²)] * [Effective roof storage depth (Obtained by converting 1000gal to ft³ and dividing it by the individual roof area in ft²)].

Under "Volume captured", the volume is defined (in acre feet) as:
[Rainwater Harvesting Infiltration & interception] – [Base Infiltration & interception]

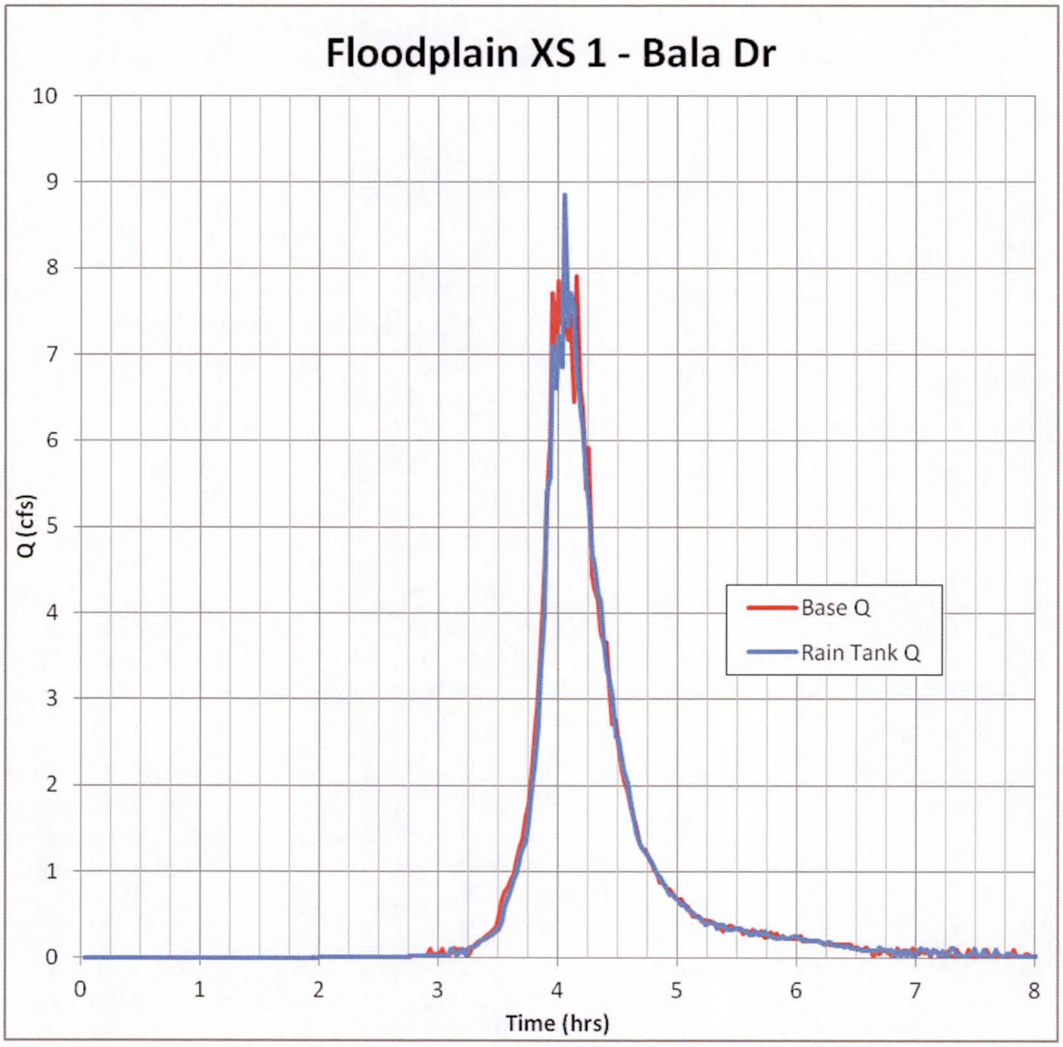
Under "Utilization of Rainwater Harvesting volume", the utilization is defined (in %) as:
[Volume captured] / [Target volume capture]

The modeling results in Table 4.5b show that modeling the roofs within the small grid model (total capacity is about 2.7% of the rainfall volume) using INFIL.DAT parameter adjustment as outlined in this memo reduce the floodplain storage and outflow. All of the potential 0.12 ac-ft LID volume is intercepted. A floodplain maximum depth difference raster is shown in Exhibit B4.

The peak flow and volume values for the cross sections are documented in Table 4.5b below and a typical floodplain cross section hydrograph is plotted below as well. Table 4.5b shows that the total surface peak flow reduction with Rainwater Harvestings is about 4% and that the total volume reduction is about 5%. All of the floodplain hydrographs are included in Appendix C4.

Table 4.5b Floodplain Cross Section Results

	Base Model		Rainwater Harvesting		Reduction			
XS	Qp	Vol	Qp	Vol	Qp		Vol	
	cfs	ac-ft	cfs	ac-ft	cfs	%	ac-ft	%
1	9.21	0.45	8.89	0.44	0.32	4	0.01	2
2	0.54	0.03	0.52	0.02	0.02	4	0.01	33
3	2.42	0.10	2.29	0.10	0.13	5	0.00	0
4	6.95	0.46	6.07	0.44	0.88	13	0.02	4
5	1.28	0.04	1.28	0.04	0.00	0	0.00	0
6	5.24	0.65	5.12	0.62	0.12	2	0.03	5
7	2.84	0.37	2.64	0.35	0.20	7	0.02	5
8	8.98	0.42	8.94	0.40	0.04	0	0.02	5
9	1.78	0.05	1.89	0.05	-0.11	-6	0.00	0
10	0.84	0.05	0.79	0.04	0.05	6	0.01	20
11	1.91	0.20	1.76	0.19	0.15	8	0.01	5
Total	41.99	2.82	40.19	2.69	1.8	4	0.13	5


Floodplain XS 1 - Bala Dr
Q (cfs)
Time (hrs)
Base Q
Rain Tank Q
0
1
2
3
4
5
6
7
8
9
10

4.6 FLO-2D Modeling Procedures for Green Roof

Spatially varied Initial Abstraction values, IA, were applied by the FLO-2D model to evaluate the impact of Green Roof LID control on the study area hydrology and hydraulics. The detailed steps are:

Step 1: Determining Parcel Design Capacities for LID Controls

In general, total LID design capacities for all the parcels within the modeling area should be estimated based on land uses and sizes according to land use zoning and the City's on-site retention requirements, such as 100-year, 2-hour on-site retention requirement. For the Green Roof LID control, the parcel specific Green Roof application areas were developed based building roof features within the modeling areas as shown in Exhibit B5. The total number of grids within Green Roof area is 8392 with total storage capacity of 0.65 ac-ft.

Step 2: Developing FLO-2D Input Data files

The steps for revising the FLO-2D input data files are as follows starting with a working base model:

1) Assign roof grids. In our model, grids overlaying building features as characterized in the surface feature data shapefile provided by FCDMC were assigned as roof grids and then spot checked. This was performed in GIS using the MGRID shapefile that can be exported from FLO-2D GDS/Mapper.

2) Parameters for INFIL.DAT – modifying the spatial parameters for roof grids

   a) ABSTRINF – The initial abstraction in inches: This value was modified based on a limitation of not being able to take more than the rainfall that falls on it. With a rainfall of 2.52 in for this simulation, the roof grids were given an IA of 2.52 in.

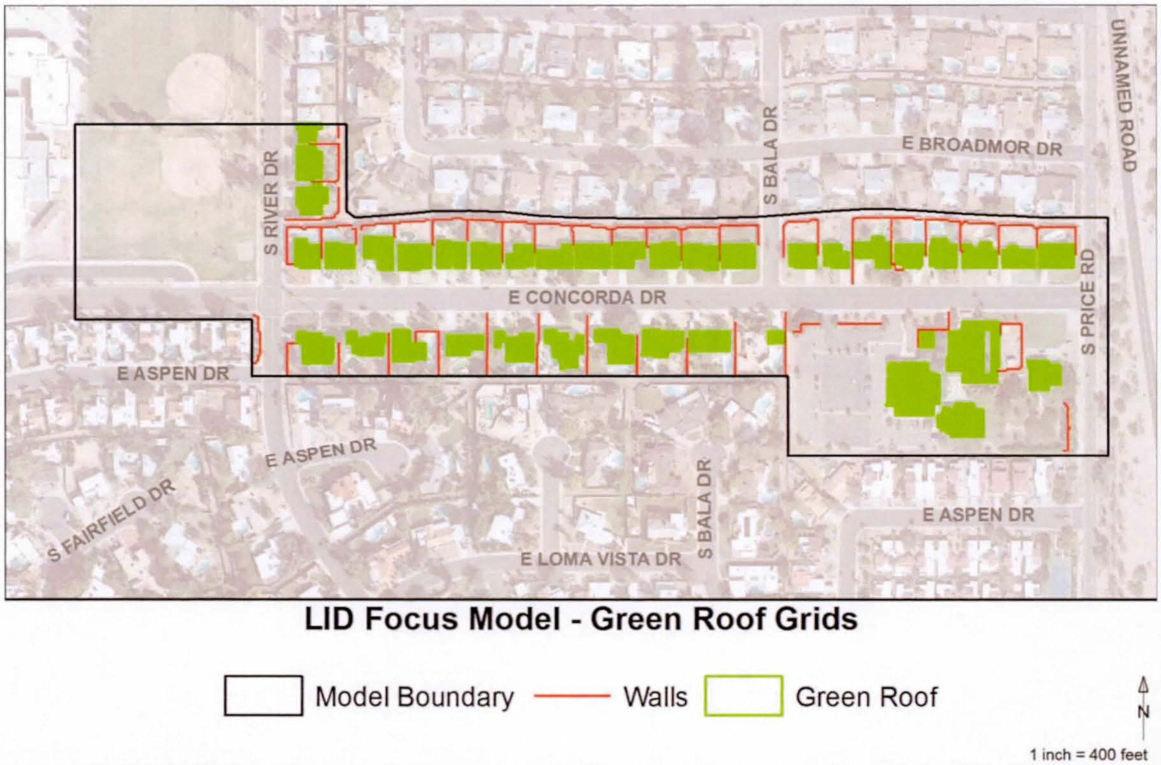
Collection of runoff:

Green roofs generally only collect water from a roof. In this modeling scenario, only roof grids were modified, so no additional routing was necessary.

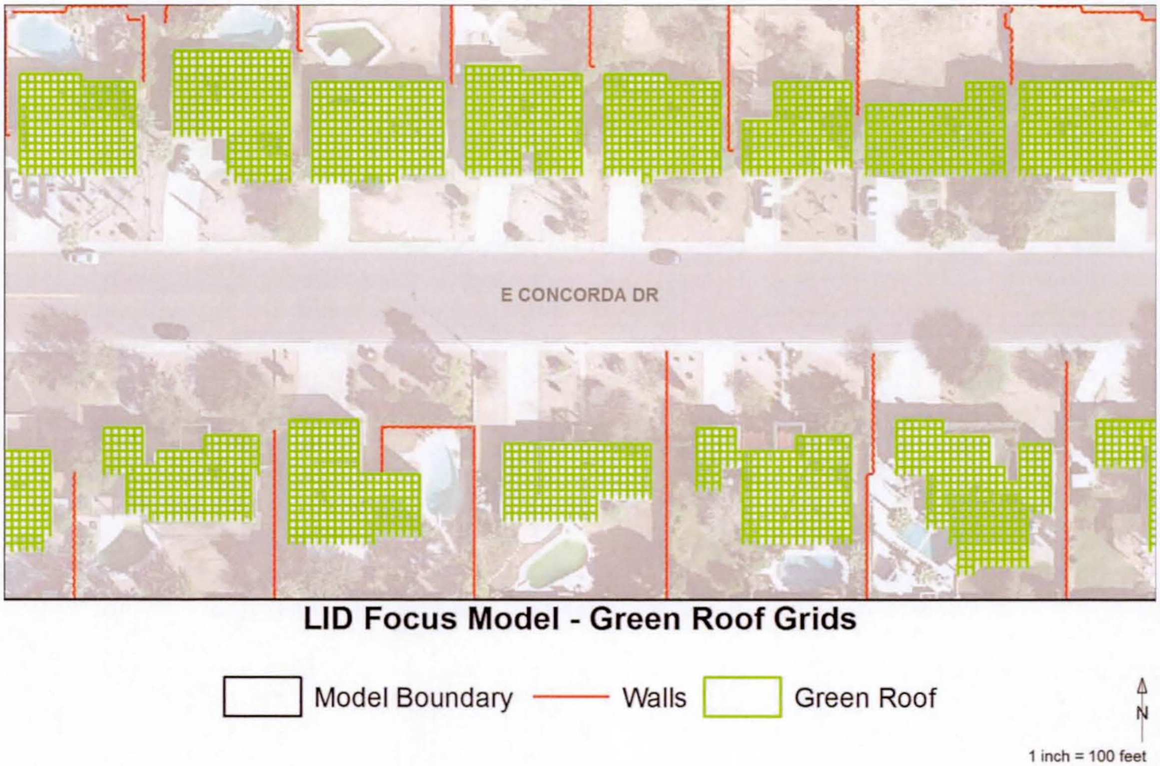
Step 3: Running FLO-2D Models and Documenting Results

A base model was developed without any LID applications (100-year, 6-hour storm model) and a model with Bio Swale LID control for all parcels was developed to simulate the effects of LID applications. The modeling results were documented in Table 4.6a.

The total LID design volume is the LID system capacity within the modeling area. The surface flow comparison values were from "SUMMARY.OUT" file and the storm drain flow comparison values were from SWMM.RPT file as shown in Table 4.6a and the numbers used were highlighted (These files were also included in Appendix C5):



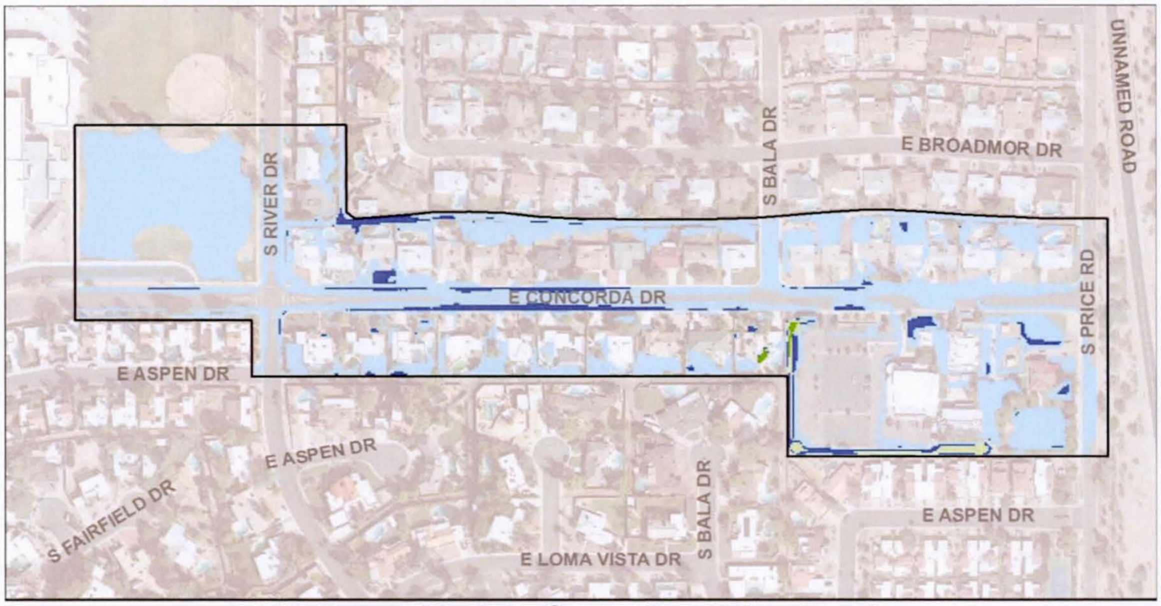
LID Focus Model - Green Roof Grids



LID Focus Model - Green Roof Grids

Table 4.6a Green Roof Modeling		Model	LID 2.1	LID 9.6
			Base	Green Roof
SWMM RPT	Outflow (Outfall node I338)	Qp (cfs)	8.58	7.85
	Wet weather inflow	V (acft)	1.19	0.93
	Return flow	V (acft)	0.04	0.02
SUMMARY OUT	Rainfall Volume	V (acft)	4.37	4.37
	Infiltration & interception	V (acft)	0.93	1.54
		%	21	35
	Floodplain storage	V (acft)	1.47	1.27
		%	34	29
	TOL storage	V (acft)	0.07	0.07
		%	2	2
	Floodplain outflow	V (acft)	0.76	0.64
		%	17	15
	Stormdrain (FLO-2D to SWMM)	V (acft)	1.23	0.92
		%	28	21
	Return flow (SWMM to FLO-2D)	V (acft)	0.03	0.01
Check	Sum of volumes	V (acft)	4.36	4.36
	Volume captured	V (acft)	-	0.61
	Target volume capture	V (acft)	-	0.63
	Utilization of Green Roof volume	%	-	96.4
	Roof grids	8392		
	Roof Area	3.08	ac	
	Roofs	40		
	Green roof volume	0.633	acft	

The maximum flow depth for the focus area and a close-up area are shown below.



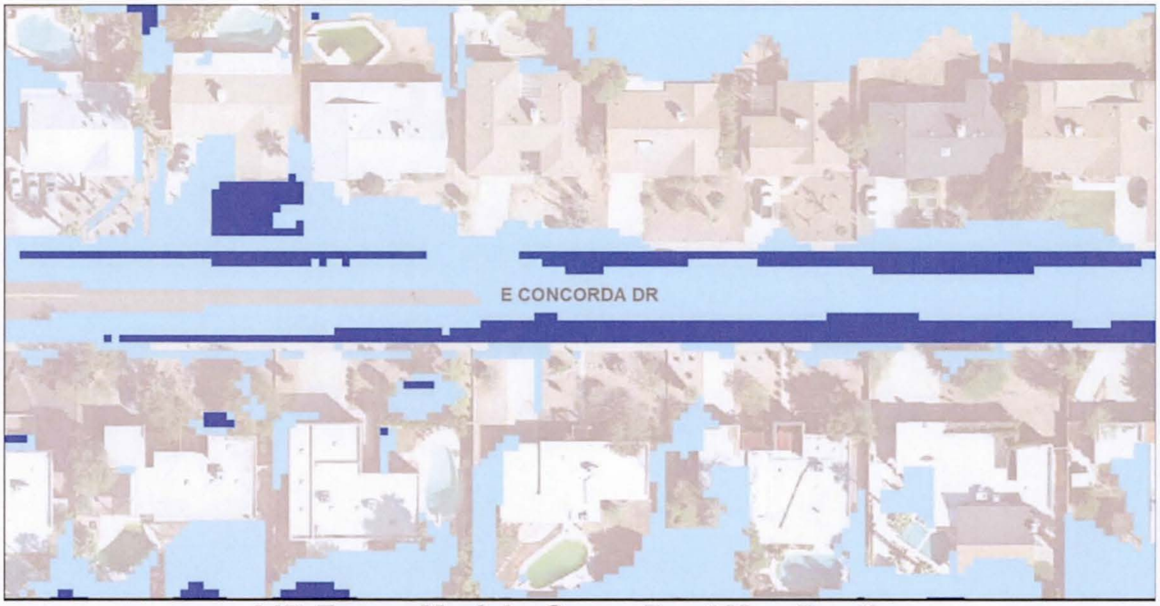
LID Focus Model - Green Roof Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 400 feet



LID Focus Model - Green Roof Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 100 feet

```
                    Abbreviated SUMMARY.OUT FILE

                 Pro Model - Build No. 15.02.10
========================================================================
                MASS BALANCE   INFLOW - OUTFLOW VOLUME
========================================================================
                    *** INFLOW (ACRE-FEET) ***
TOTAL POINT RAINFALL:                                  2.5200 INCHES
                                                    WATER
RAINFALL VOLUME                                        4.37
SURFACE WATER INFLOW HYDROGRAPH                      0.00
                                                  ---------
INFLOW HYDROGRAPHS + RAINFALL                          4.37
=======================================================================
                    *** SURFACE OUTFLOW (ACRE-FT) ***
OVERLAND INFILTRATED AND INTERCEPTED WATER       1.27 INCHES
          OVERLAND FLOW                             WATER
WATER LOST TO INFILTRATION & INTERCEPTION              1.54
FLOODPLAIN STORAGE                                     1.27
OVERLAND STORAGE DUE TO TOL                            0.07
FLOODPLAIN OUTFLOW HYDROGRAPH                          0.64
                                                  ---------
FLOODPLAIN OUTFLOW, INFILTRATION & STORAGE             3.46
TOTAL SURFACE OUTFLOW AND STORAGE                      1.91
========================================================================
          *** FLO-2D STORM DRAIN EXCHANGE VOLUME (ACRE-FT) ***
FLO-2D TO SWMM THROUGH INLETS                          0.92
SWMM TO FLO-2D FROM RETURNING FLOW                     0.01
SWMM TO FLO-2D FROM OUTFALL                            0.00
FLO-2D TO SWMM FROM OUTFALL                            0.00
                                                  ---------
NET VOLUME                                             0.91
========================================================================
                          *** TOTALS ***
TOTAL OUTFLOW FROM GRID SYSTEM                         0.64
TOTAL VOLUME OF OUTFLOW AND STORAGE                    4.37

  SURFACE AREA OF INUNDATION REGARDLESS OF THE TIME OF OCCURRENCE:
(FOR FLOW DEPTHS GREATER THAN THE "TOL" VALUE TYPICALLY 0.1 FT OR 0.03 M)

THE MAXIMUM INUNDATED AREA IS:                           17.96 ACRES
========================================================================
     COMPUTER RUN TIME IS:  3.14502 HRS
     THIS OUTPUT FILE WAS TERMINATED ON:  10/16/2015  AT:  11:37:48
```

Abbreviated SWMM.rpt

```
EPA STORM WATER MANAGEMENT MODEL - VERSION 5.0 (Build 5.0.022)
--------------------------------------------------------------
Element Count
*************
Number of nodes ........... 6
Number of links ........... 5

Control Actions Taken
**************************        Volume         Depth
Runoff Quantity Continuity     acre-feet        inches
Total Precipitation ......         0.000         0.000
Evaporation Loss .........         0.000         0.000
Infiltration Loss ........         0.000         0.000
Surface Runoff ...........         0.000         0.000
Final Surface Storage ....         0.000         0.000
Continuity Error (%) .....         0.000

**************************        Volume        Volume
Flow Routing Continuity        acre-feet      10^6 gal
Dry Weather Inflow .......         0.000         0.000
Wet Weather Inflow .......         0.933         0.304
Groundwater Inflow .......         0.000         0.000
RDII Inflow ..............         0.000         0.000
External Inflow ..........         0.000         0.000
External Outflow .........         0.901         0.294
Internal Outflow .........         0.021         0.007
Storage Losses ...........         0.000         0.000
Initial Stored Volume ....         0.000         0.000
Final Stored Volume ......         0.002         0.001
Continuity Error (%) .....         0.986

Outfall Loading Summary
***********************
                      Flow       Avg.       Max.       Total
                      Freq.      Flow       Flow      Volume
Outfall Node          Pcnt.       CFS        CFS    10^6 gal
I388                  88.67      1.03       7.85       0.294
-----------------------------------------------------------
System                88.67      1.03       7.85       0.294

Analysis begun on:  Fri Oct 16 08:28:45 2015
Analysis ended on:  Fri Oct 16 11:37:28 2015
Total elapsed time: 03:08:43
```

Under "Sum of volumes", the volume is defined (in acre feet) as:
[Infiltration & interception] + [Floodplain storage] + [TOL storage] + [Floodplain outflow] + [Stormdrain]. This value should match the rainfall volume. Any difference within 0.01ac-ft may be due to rounding error.

Under "Target volume capture", the volume is defined (in acre feet) as:
[# of roof grids (8392)] * [grid area (4 ft*4 ft=16ft^2)] * [Effective green roof storage depth (rainfall depth = 2.52 in)].

Under "Volume captured", the volume is defined (in acre feet) as:
[Green Roof Infiltration & interception] – [Base Infiltration & interception]

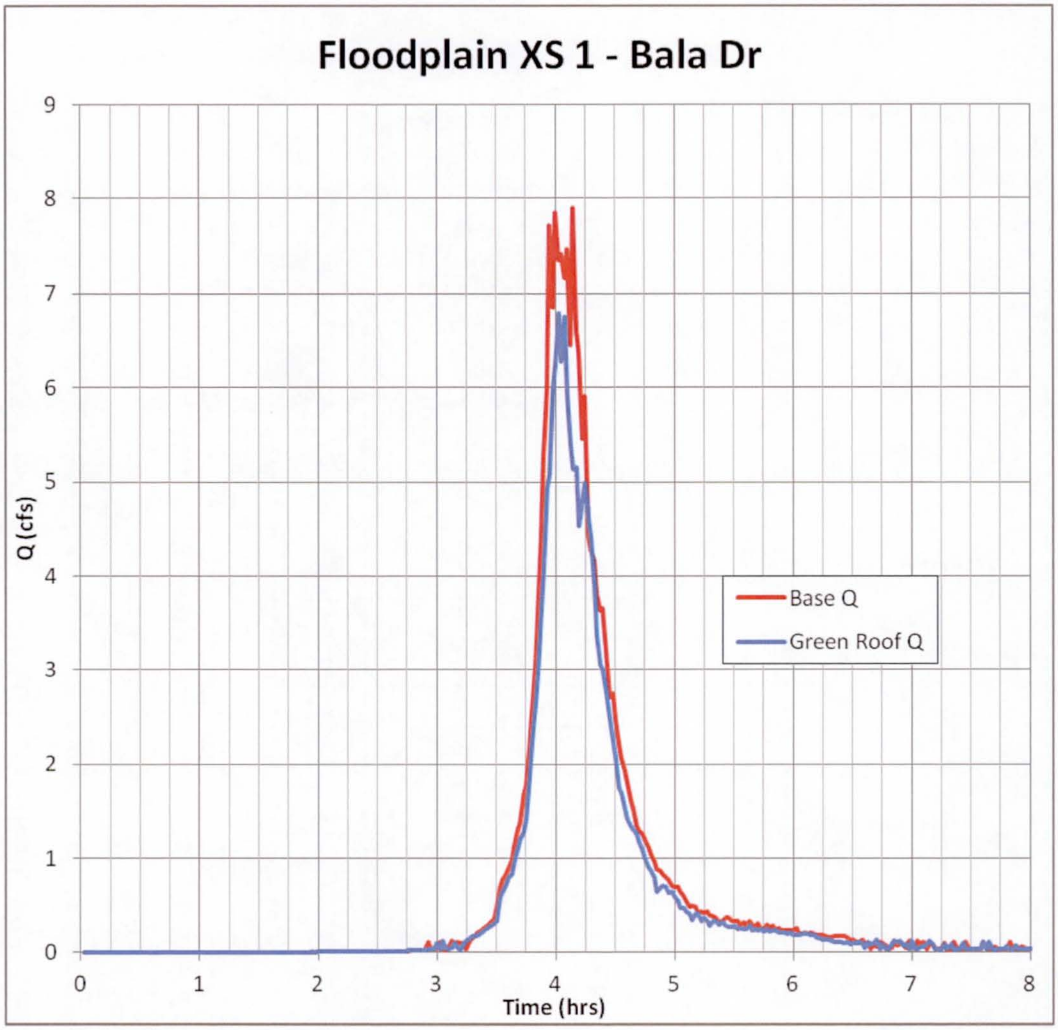
Under "Utilization of green roof volume", the utilization is defined (in %) as:
[Volume captured] / [Target volume capture]

The modeling results in Table 4.6a show that modeling the roofs within the small grid model (total capacity is about 14.8% of the rainfall volume) using INFIL.DAT parameter adjustment as outlined in this memo reduce the floodplain storage, outflow, as well as the stormdrain outflow. Of a potential 0.65 ac-ft, the model infiltrates 0.61 ac –ft (95%). A floodplain maximum depth difference raster is shown in Exhibit B5.

The peak flow and volume values for the cross sections are documented in Table 4.6b below and a typical floodplain cross section hydrograph is plotted below as well. Table 4.6b shows that the total surface peak flow reduction with green roofs is about 20% and that the total volume reduction is about 22%. All of the floodplain hydrographs are included in Appendix C5.

Table 4.6b Floodplain Cross Section Results

	Base Model		Green Roof		Reduction			
XS	Qp	Vol	Qp	Vol	Qp		Vol	
	cfs	ac-ft	cfs	ac-ft	cfs	%	ac-ft	%
1	9.21	0.45	7.88	0.38	1.33	14	0.07	16
2	0.54	0.03	0.40	0.02	0.14	26	0.01	33
3	2.42	0.10	2.48	0.10	-0.06	-3	0.00	0
4	6.95	0.46	5.46	0.35	1.49	21	0.11	24
5	1.28	0.04	1.30	0.04	-0.02	-2	0.00	0
6	5.24	0.65	3.64	0.50	1.60	31	0.15	23
7	2.84	0.37	2.10	0.27	0.74	26	0.10	27
8	8.98	0.42	7.51	0.35	1.47	16	0.07	17
9	1.78	0.05	1.16	0.04	0.62	35	0.01	20
10	0.84	0.05	0.54	0.03	0.30	36	0.02	40
11	1.91	0.20	1.29	0.13	0.62	33	0.07	35
Total	41.99	2.82	33.76	2.21	8.23	20	0.61	22

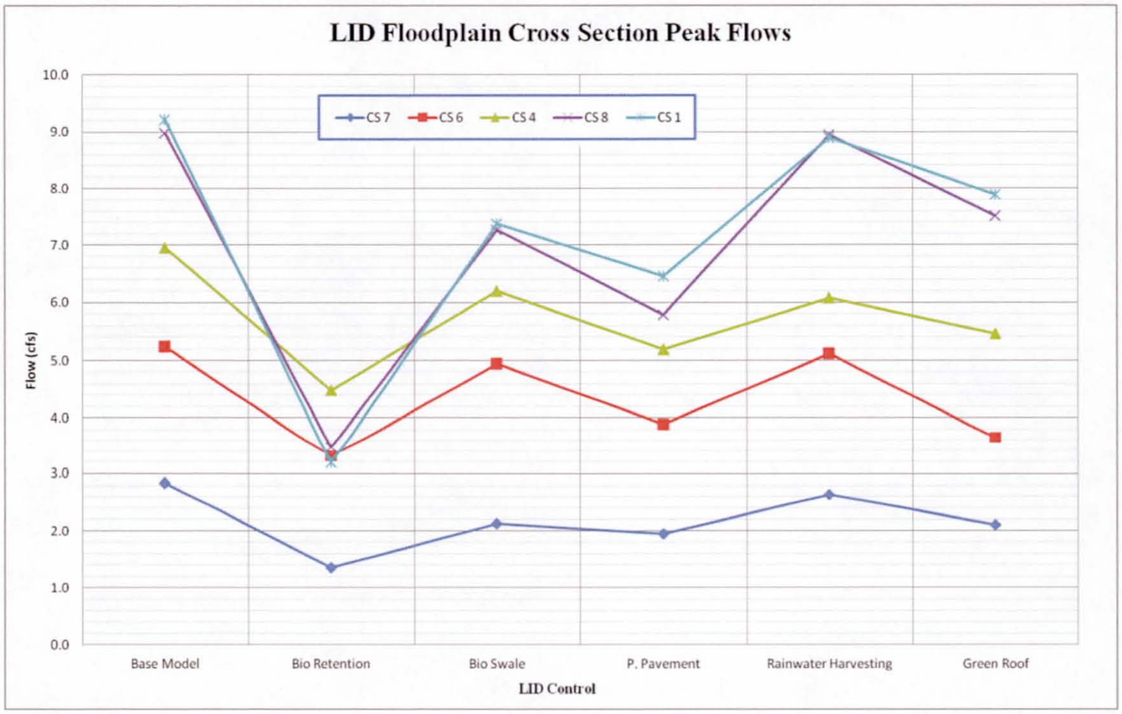

Floodplain XS 1 - Bala Dr
Q (cfs)
Time (hrs)
0
1
2
3
4
5
6
7
8
9
Base Q
Green Roof Q

4.7 Summary of Modeling Results for Five LID Controls

The FLO-2D modeling results for the base model and the five basic LID controls are summarized in Table 4.7. Table 4.7 shows that Rainwater Harvesting and Green Roof have highest utilization rates as expected; Pervious Pavement and Bio Retention have high utilization rates as well; and Bio Swale has lowest utilization in terms of storm volume reduction. These utilization effectiveness factors will be applied for the determination of the LID design capacities in the regional FLO-2D modeling of the LID application scenarios. Bio Retention has the highest peak flow reductions in all cross sections as shown in the following chart. The modeling results further strengthened the conclusion that Initial Loss IA Adjustment is the most appropriate method among the potential modeling techniques.

Table 4.7 Summary Table for LID Basic Control Modeling Results

		Model	LID 2.1	LID 6.5	LID 13	LID 7.3	LID 9.3	LID 9.6
			Base	Bio Retention	Bio Swale	Pervious Pavement	Rainwater Harvesting	Green Roof
SWMM RPT	Outflow (Outfall node I338)	Qp (cfs)	8.58	4.70	8.45	7.52	8.62	7.85
	Wet weather inflow	V (acft)	1.19	0.64	1.11	1.02	1.15	0.93
	Return flow	V (acft)	0.04	0.00	0.03	0.02	0.04	0.02
SUMMARY OUT	Rainfall volume (2.52" depth)	V (acft)	4.37	4.37	4.37	4.37	4.37	4.37
	Infiltration & interception	V (acft)	0.93	1.32	0.99	1.67	1.05	1.54
		%	21	30	23	38	24	35
	Floodplain storage	V (acft)	1.47	1.83	1.5	1.09	1.44	1.27
		%	34	42	34	25	33	29
	TOL storage	V (acft)	0.07	0.07	0.07	0.07	0.07	0.07
		%	2	2	2	2	2	2
	Floodplain outflow	V (acft)	0.76	0.58	0.79	0.59	0.73	0.64
		%	17	13	18	14	17	15
	Stormdrain (FLO-2D to SWMM)	V (acft)	1.23	0.64	1.1	1.02	1.17	0.92
		%	28	15	25	23	27	21
	Return flow (SWMM to FLO-2D)	V (acft)	0.03	0.00	0.02	0.00	0.02	0.01
Vol Comparison	Sum of volumes	V (acft)	4.36	4.37	4.36	4.37	4.37	4.36
	LID volume captured	V (acft)	-	0.75	0.09	0.74	0.12	0.61
	LID design volume capacity	V (acft)	-	0.89	0.31	0.85	0.12	0.63
	Utilization of LID volume	%	-	84	29	87	98	96

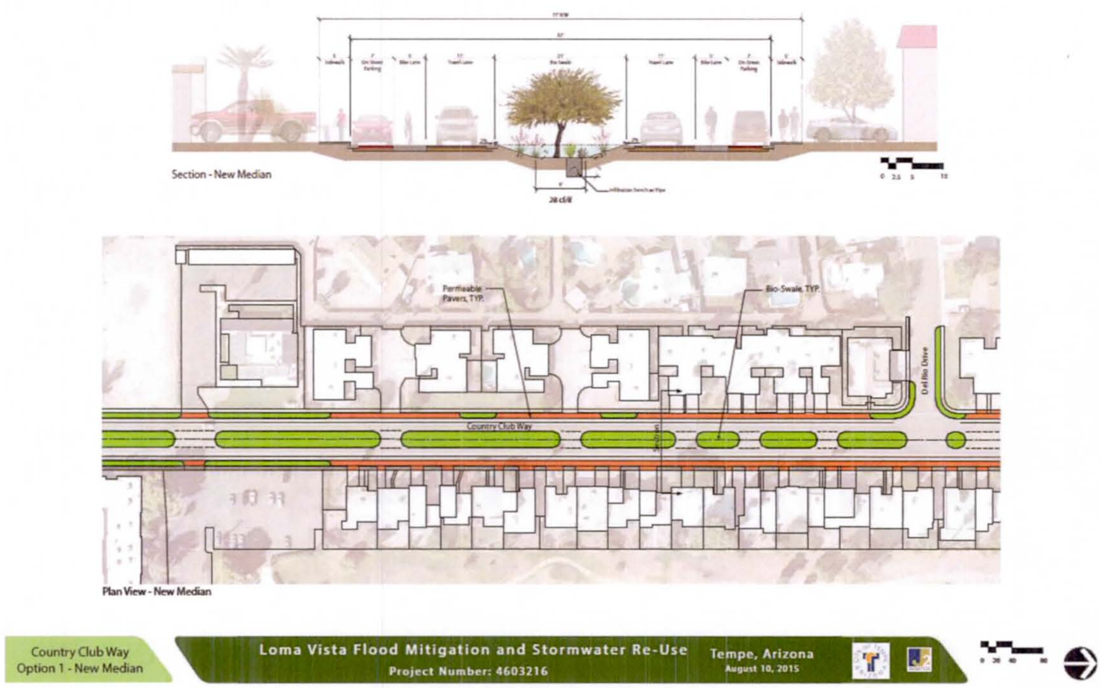

LID Floodplain Cross Section Peak Flows
CS 7
CS 6
CS 4
CS 8
CS 1
Flow (cfs)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Base Model
Bio Retention
Bio Swale
P. Pavement
Rainwater Harvesting
Green Roof
LID Control

5.0 SIMULATION OF LID CONTROL COMBINATIONS

5.1 Selection of LID Control Combinations/Systems

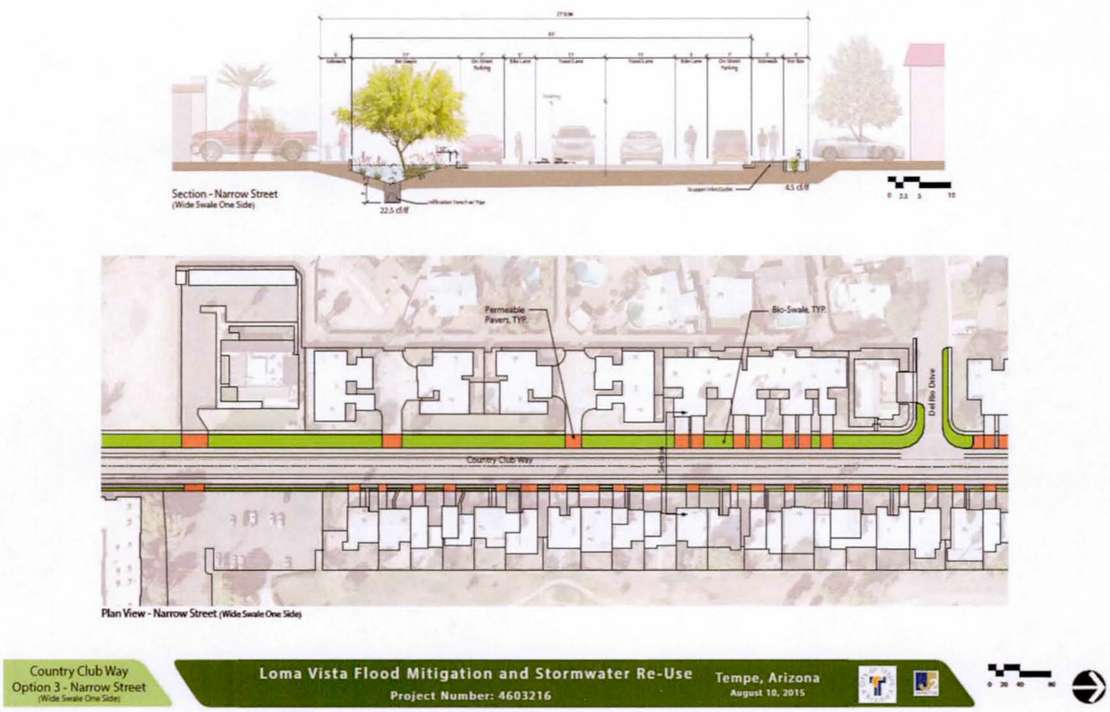
A LID control system is defined as a combination of at least one LID control with LID accessories and certain parcel participation rate (percentage of properties joining LID practices).

Many LID application options were evaluated for the Focus Area as well as within Loma Vista Area. Several examples are shown in the following plans and pictures, and they are also included in Exhibit C0. These applications include LID practices along Concorda Drive within the Focus Area and Country Club Way within Loma Vista Area. The effectiveness of the LID system is dependent on the types of controls as well as parcel participation rate.

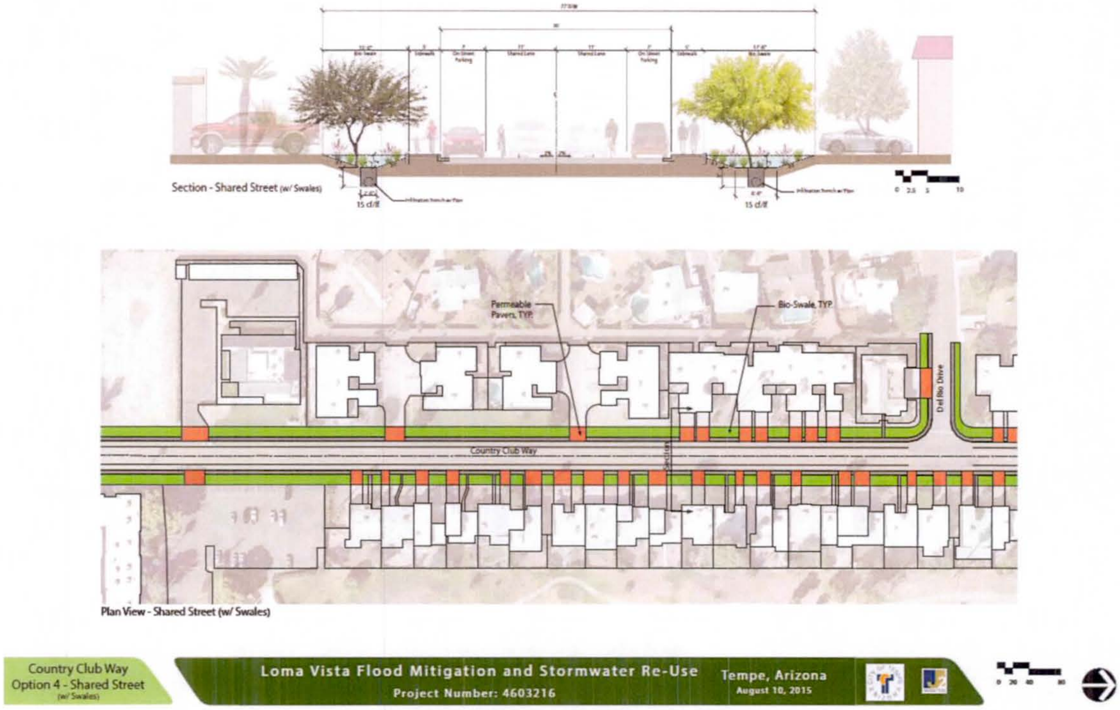


Excerpt from Exhibit C0

Excerpt from Exhibit C0



Excerpt from Exhibit C0



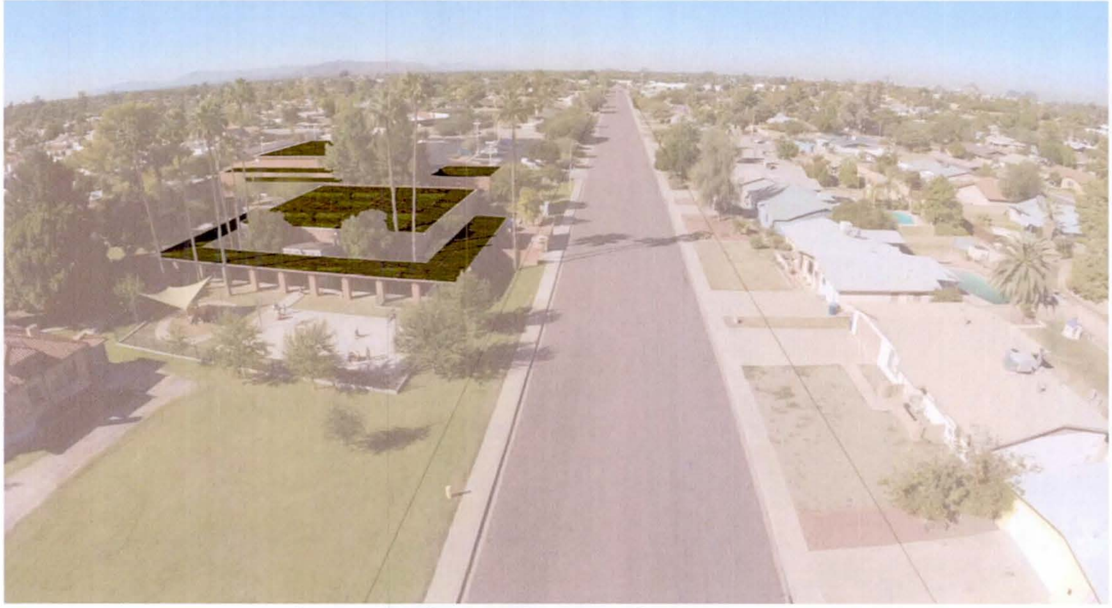
Excerpt from Exhibit C0

Bio Retention along Concorda Drive

Bio Swale along Concorda Drive

Pervious Pavement along Concorda Drive


Rainwater Harvesting example along Concorda Drive


Green Roof example along Concorda Drive

LID Combination example along Concorda Drive

J2 evaluated numerous LID combinations for the project. They selected three (3) LID control combinations to demonstrate the FLO-2D modeling techniques and the effectiveness of LID applications on flood mitigation. These three LID systems are common and acceptable practices for Tempe and they are: On-Lot Treatment System, Green Park System, and Green Street System. The following sub-sections document the modeling procedures and results for these three systems. The FLO-2D model for the Focus Area was used for the modeling of these three systems.

5.2 On-Lot Treatment System

On-Lot Treatment System consists of a series of bio retention, bio swale, and rainwater harvesting (rain tanks) with various accessories. The land uses for this system are primarily residential. The general concept of this system along Concorda Drive within the Focus Area is shown in the following photo.

On-Lot Treatment System Concept along Concorda Drive

On Lot Treatment System FLO-2D Modeling Procedures:
In addition to grid elevation adjustments for the grids within the LID system areas, spatially varied initial abstractions, infiltration rates, and limiting soil depths were applied by the FLO-2D model to evaluate the impact of this system on the study area hydrology and hydraulics. The detailed steps are:

1) Selection of FLO-2D Grids for On Lot Treatment LID System:
   - Building roofs for rainwater harvesting – same as rainwater harvesting control selection
   - Bio retention – same as bio retention control grids for storage areas and curb cuts as hydraulic structures
   - Bio swale – single row of grids nearest the street to connect the bio retention grid groups

2) FLO-2D Input Parameter Modifications:
   - Roof grids – INFIL.DAT – IA given value to reflect 100yr-2hr storm (2.16 in capacity for all roof grids
   - Bio retention – FPLAIN.DAT, INFIL.DAT, HYSTRUC.DAT – same as bio retention control grids
   - Bio swale – FPLAIN.DAT, INFIL.DAT – Elevations at endpoints of the rows were set at 0.5 ft above the bio retention elevation and grid elevations are interpolated between these. Since the regional drainage flows from east to west and from south to north in this area, checks were made to prevent negative slope profiles in those directions

3) Estimation of Added Volume Capacity:

- Increase in initial abstraction depths:
  Sum of Depths (ΔΣ [ABSTRINF]) * Grid Area (16 ft^2)

- Increase in limiting soil depths:
  Sum of Depths (ΔΣ [SOILD*DTHETA]) * Grid Area (16 ft^2)

- Increase in volume on surface storage:
  Sum of Depths (-ΔΣ [Elevation]) * Grid Area (16 ft^2)

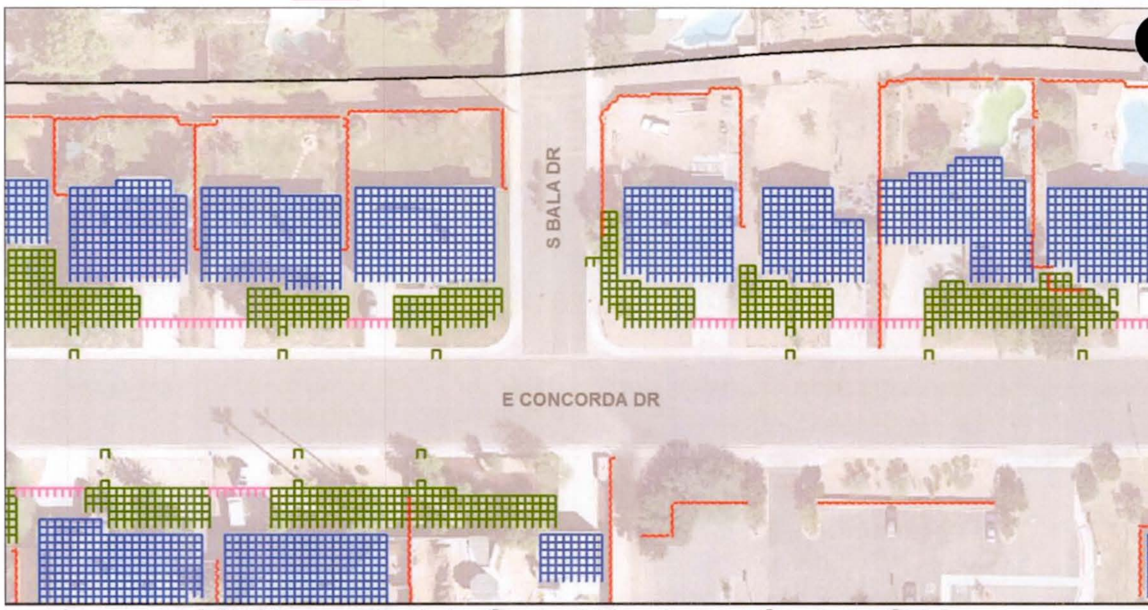
The exhibit showing the on lot treatment system LID areas and FLO-2D grids is included in Exhibit C1. The FLO-2D model input and output files, hydrographs, GIS post-processing, and output files used for modeling summary results are included in Appendix D1. The FLO-2D modeling results summary data is documented in Table 5.1 and the comparison of cross section hydrographs from the three (3) LID systems is shown in Figure 5.1.

LID Focus Model - On Lot Treatment System Grids

Bio Retention | Model Boundary
Rainwater Harvesting | Walls
Bio Swale

N

1 inch = 400 feet



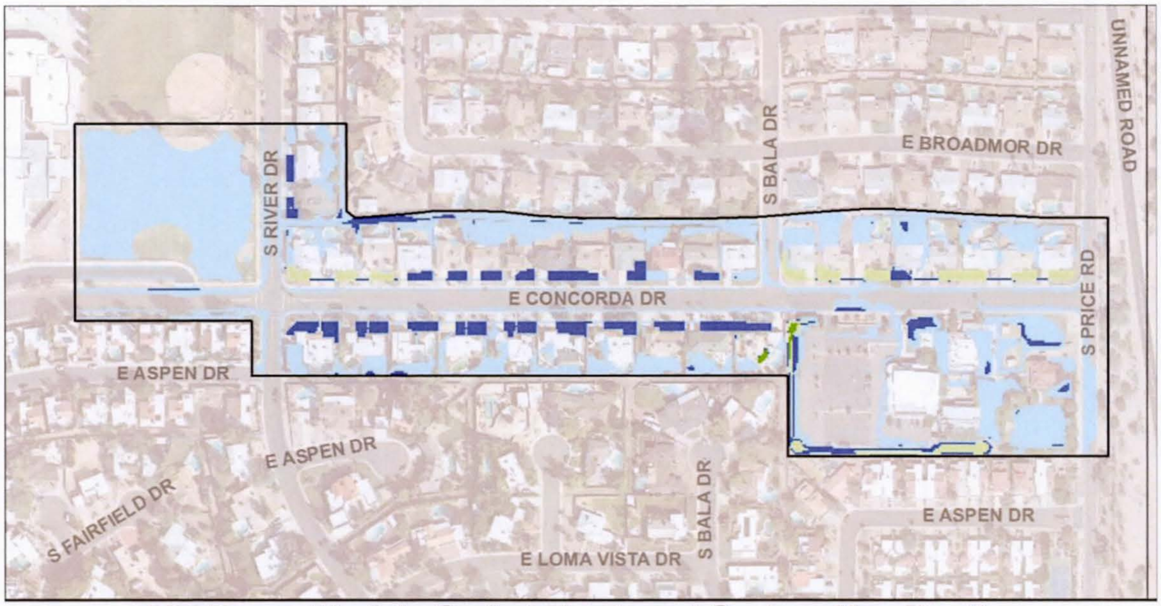
LID Focus Model - On Lot Treatment System Grids

Bio Retention | Model Boundary
Rainwater Harvesting | Walls
Bio Swale

N

1 inch = 100 feet

The maximum flow depth for the on lot treatment area and a close-up area are shown below.



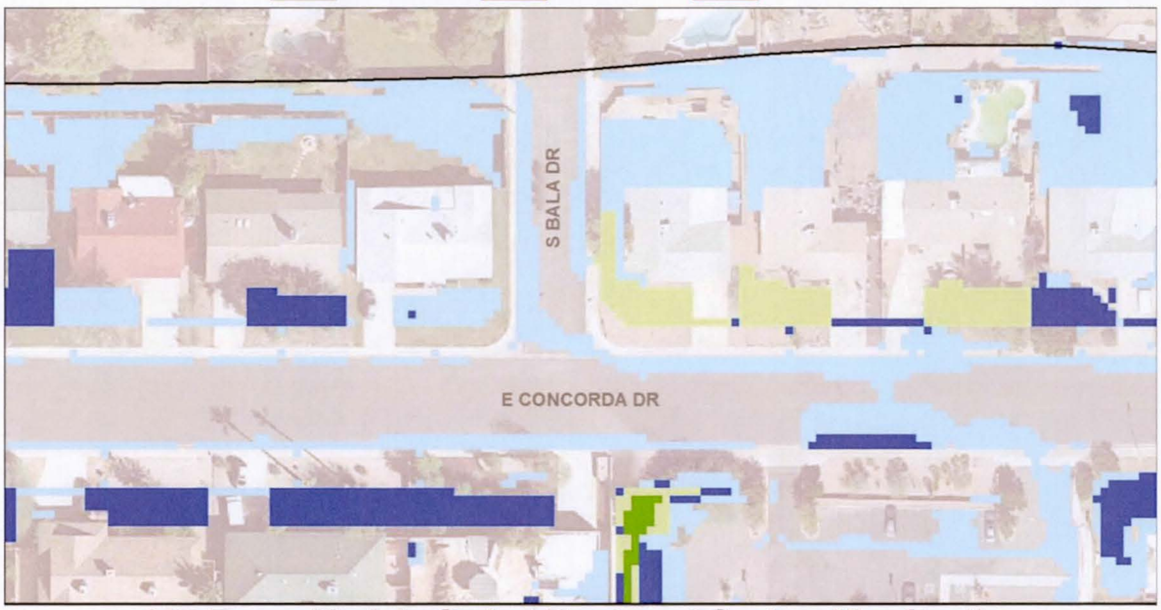
LID Focus Model - On Lot Treatment System Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10
0.11 - 0.50
0.51 - 1.00
1.01 - 2.00
2.01 - 4.00
4.01 - 6.00
6.01 - 8.00
8.01 - 10.00
10.01 +

N

1 inch = 400 feet



LID Focus Model - On Lot Treatment System Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10
0.11 - 0.50
0.51 - 1.00
1.01 - 2.00
2.01 - 4.00
4.01 - 6.00
6.01 - 8.00
8.01 - 10.00
10.01 +

N

1 inch = 100 feet

5.3 Green Parking System

Green Parking System consists of a series of bio retention, bio swale, and pervious pavement with various accessories. The land uses for this system are primarily commercial, community parking lots, and residential driveways. The general concept of this system Concorda Drive within the Focus Area is shown in the following photo.

Green Parking System Concept along Concorda Drive

Green Parking System FLO-2D Modeling Procedures:

In addition to grid elevation adjustments for the grids within the LID system areas, spatially varied initial abstractions, infiltration rates, and limiting soil depths were applied by the FLO-2D model to evaluate the impact of this system on the study area hydrology and hydraulics. The detailed steps are:

1) Selection of FLO-2D Grids for Green Parking LID System:
   - Residential driveways – same as pervious pavement control selection, with added walls too
   - Church site and school driveway were used as pervious pavement
   - Bio retention – manually selected areas near the church parking lot and school driveway
   - Routing to bio retention – grids connecting street drainage to bio retention area

2) FLO-2D Input Parameter Modification:
   - Residential driveways INFIL.DAT – same as LID controls

- Church site and school driveway – INFIL.DAT – same as LID controls

- Bio retention – INFIL.DAT, FPLAIN.DAT – Bio retention areas were defined with interior, exterior, and connection grids. Interior grids were those not on perimeters of the basins, and were lowered by 2 ft, n-value increased to 0.1, and infiltration capacity was increased by 0.5 ft similar to the infiltration parameters used in the bio retention control model. Exterior grids were only lowered by 1 ft and n-values were increased to 0.1. Connector grids were manually lowered in order to provide a route to the basin

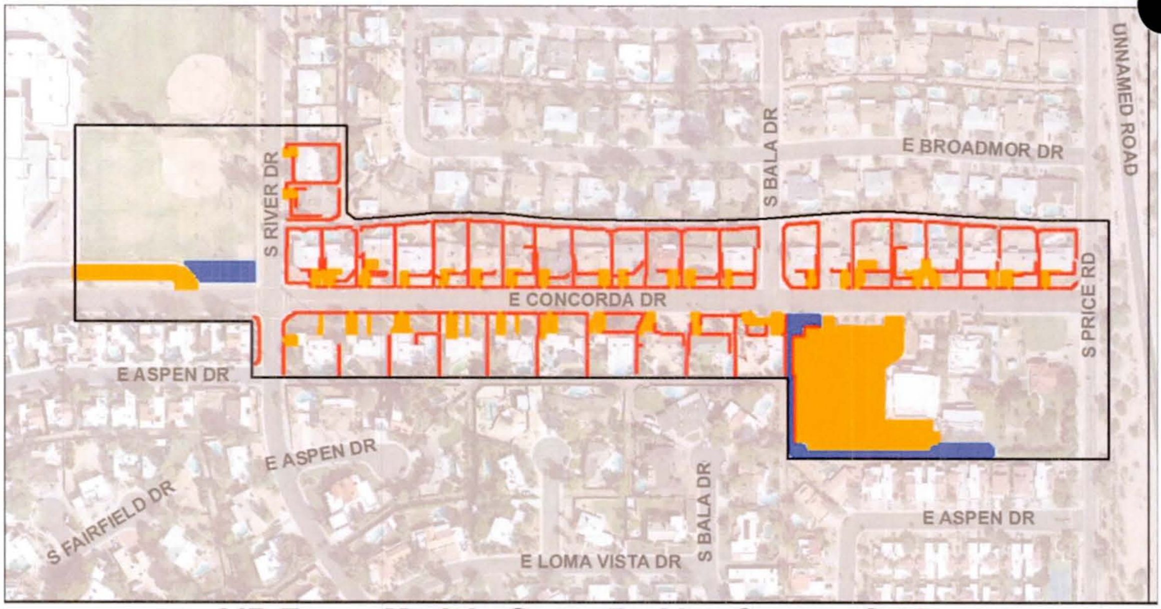
3) Estimation of Added Volume Capacity:

- Increase in initial abstraction depths:
  Sum of Depths (ΔΣ [ABSTRINF]) * Grid Area (16 ft^2)

- Increase in limiting soil depths:
  Sum of Depths (ΔΣ [SOILD*DTHETA]) * Grid Area (16 ft^2)

- Increase in volume on surface storage:
  Sum of Depths (-ΔΣ [Elevation]) * Grid Area (16 ft^2)

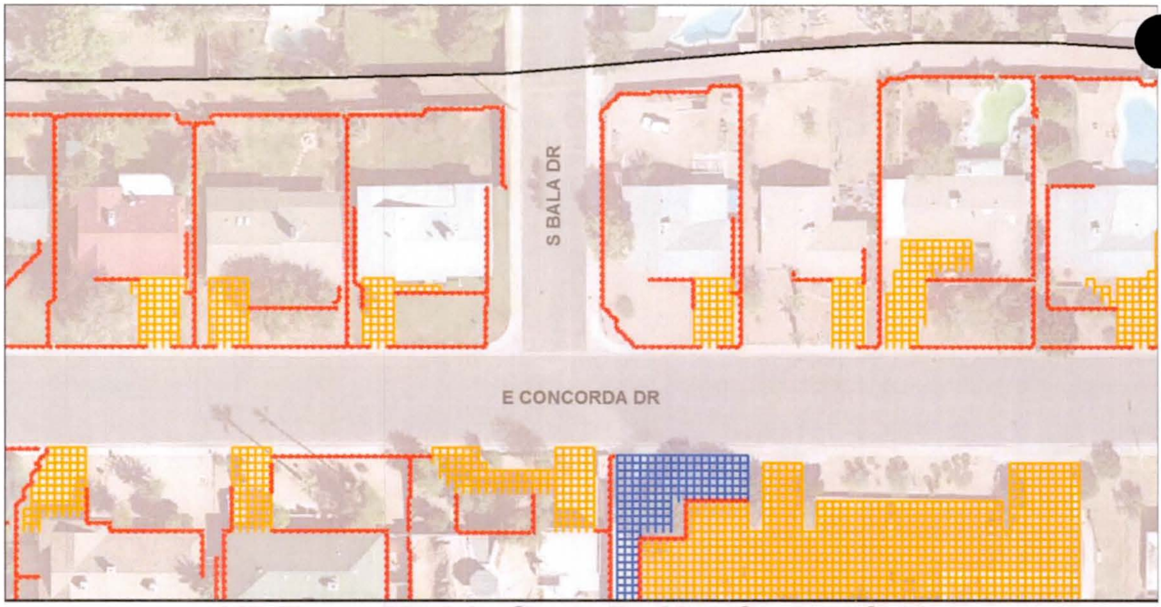
The exhibit showing the green parking system LID areas and FLO-2D grids is included in Exhibit C2. The FLO-2D model input and output files, hydrographs, GIS post-processing, and output files used for modeling summary results are included in Appendix D2. The FLO-2D modeling results summary data is documented in Table 5.1 and the comparison of cross section hydrographs from the three (3) LID systems is shown in Figure 5.1.



LID Focus Model - Green Parking System Grids

Pervious Pavement — Model Boundary
Bio Retention — Walls

N
1 inch = 400 feet

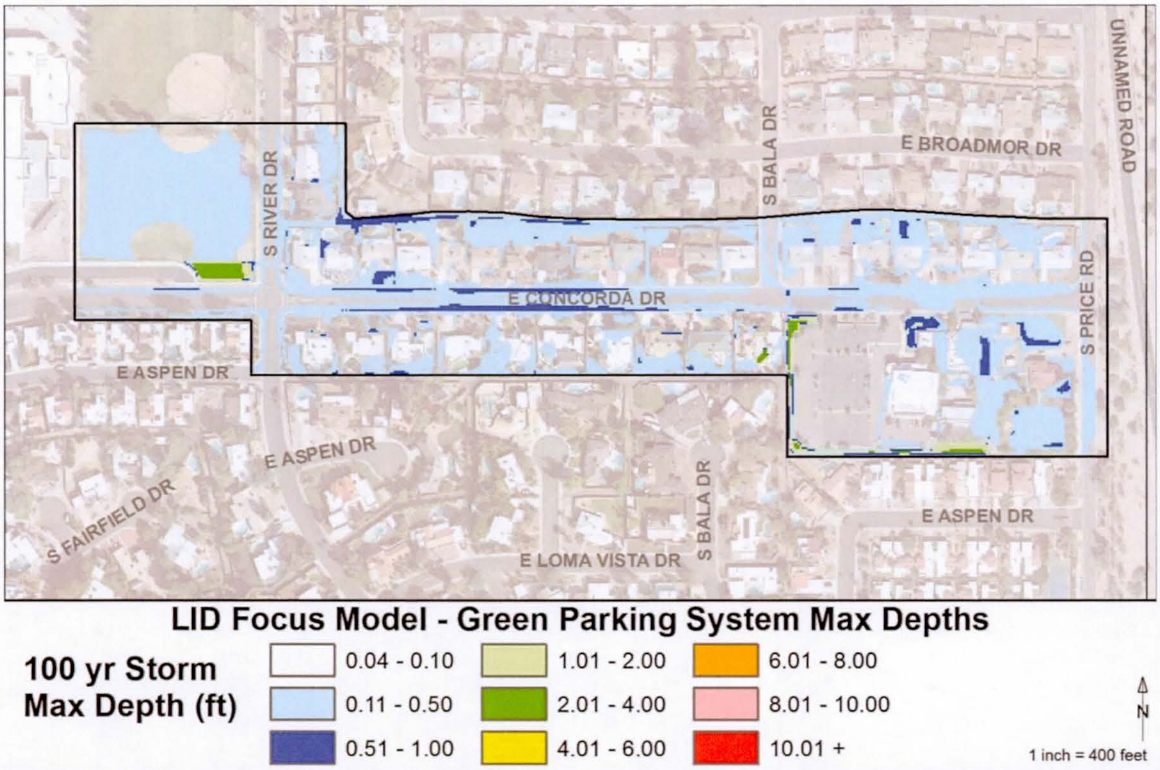


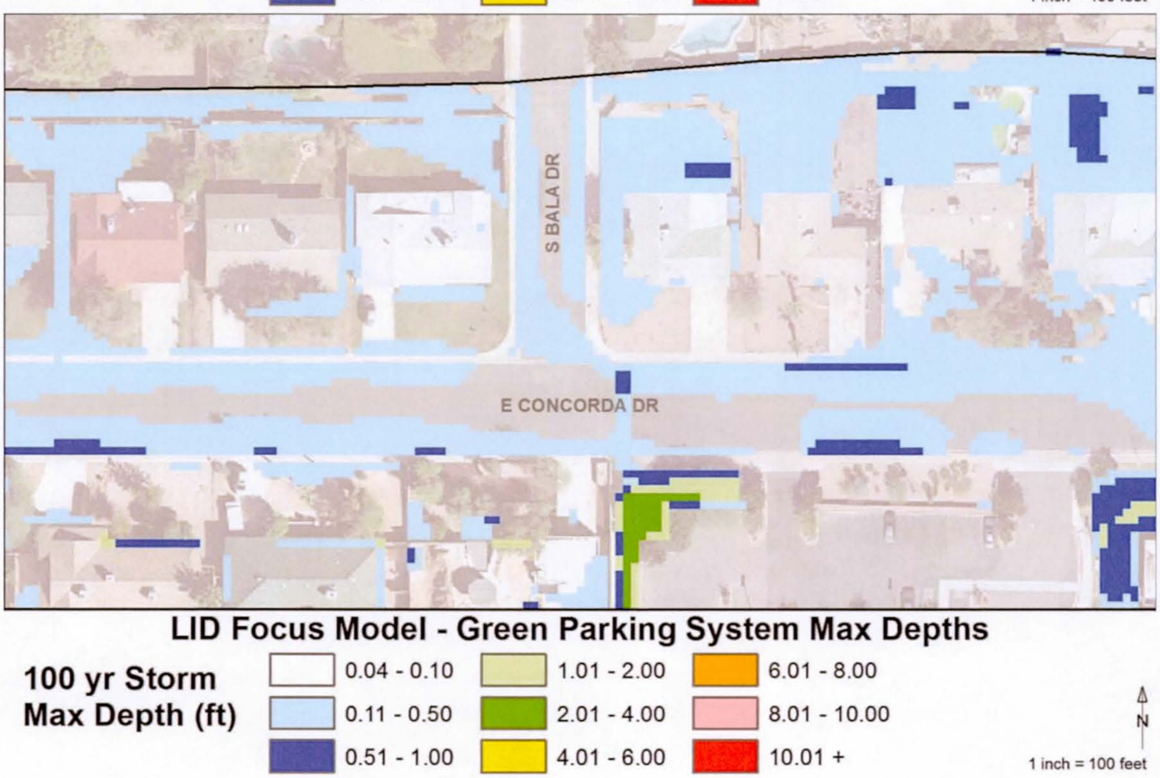
LID Focus Model - Green Parking System Grids

Pervious Pavement — Model Boundary
Bio Retention — Walls

N
1 inch = 100 feet

The maximum flow depth for the green parking area and a close-up area are shown below.





5.4 Green Street System

Green Street System consists of a series of bio retention, bio swale, and pervious pavement with various accessories. The land uses for this system are primarily streets, public right-of-ways, and some residential land adjacent to streets. The general concept of this system along Concorda Drive within the Focus Area is shown in the following photo.

Green Street System Concept along Concorda Drive

Green Street System FLO-2D Modeling Procedures:

In addition to grid elevation adjustments for the grids within the LID system areas, spatially varied initial abstractions, infiltration rates, and limiting soil depths were applied by the FLO-2D model to evaluate the impact of this system on the study area hydrology and hydraulics. The detailed steps are:

1) Selection of FLO-2D Grids for Green Street LID System:
   - Bio swale – double row of grids on the curbs of the streets – broken up by driveways
   - Pervious pavement – double row of grids adjacent to the bio swales and double rows of grids between bio swales that are broken up by driveways
   - Bio retention – same grids used in green parking system model

2) FLO-2D Input Parameter Modification:
   - Bio swale – Grid elevations dropped by 1 ft, infiltration matches control model parameters
   - Pervious pavement – matches control model parameters

- Bio retention – INFIL.DAT, FPLAIN.DAT – Bio retention areas were defined with interior, exterior, and connection grids. Interior grids were those not on perimeters of the basins, and were lowered by 1 ft, n-value increased to 0.1, and infiltration capacity was increased by 0.5 ft similar to the infiltration parameters used in the bio retention control model. Exterior grids were only lowered by 0.5 ft and n-values were increased to 0.1. Connector grids were manually lowered in order to provide a route to the basin

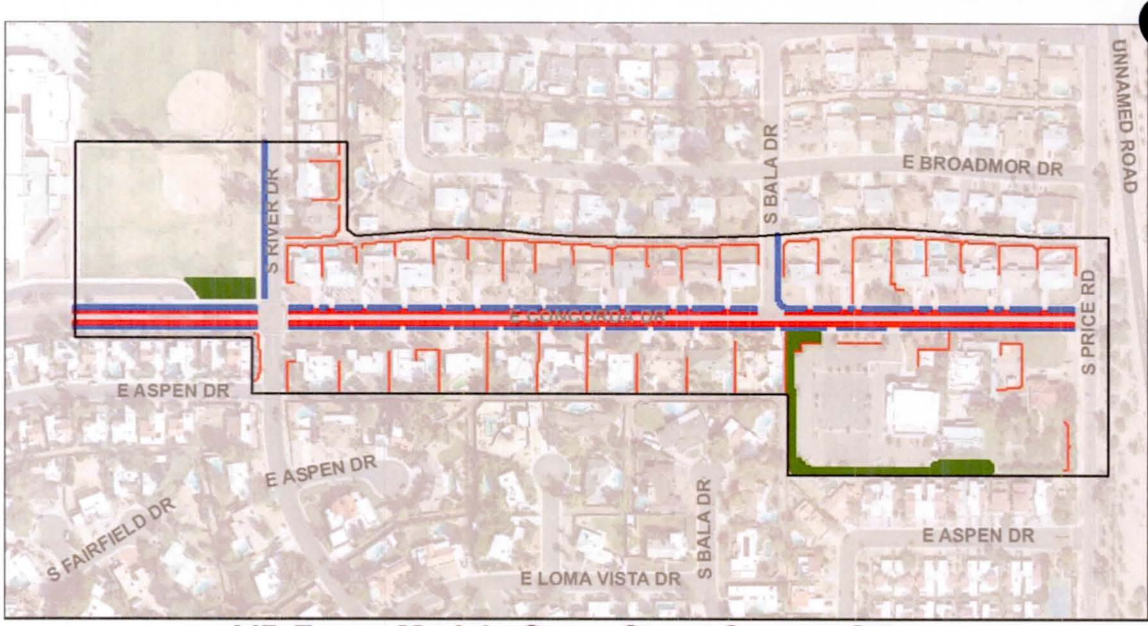
3) Estimation of Added Volume Capacity:

- Increase in initial abstraction depths:
  Sum of Depths (ΔΣ [ABSTRINF]) * Grid Area (16 ft^2)

- Increase in limiting soil depths:
  Sum of Depths (ΔΣ [SOILD*DTHETA]) * Grid Area (16 ft^2)

- Increase in volume on surface storage:
  Sum of Depths (-ΔΣ [Elevation]) * Grid Area (16 ft^2)

The exhibit showing the green street system LID areas and FLO-2D grids is included in Exhibit C3. The FLO-2D model input and output files, hydrographs, GIS post-processing, and output files used for modeling summary results are included in Appendix D3. The FLO-2D modeling results summary data is documented in Table 5.1 and the comparison of cross section hydrographs from the three (3) LID systems is shown in Figure 5.1.

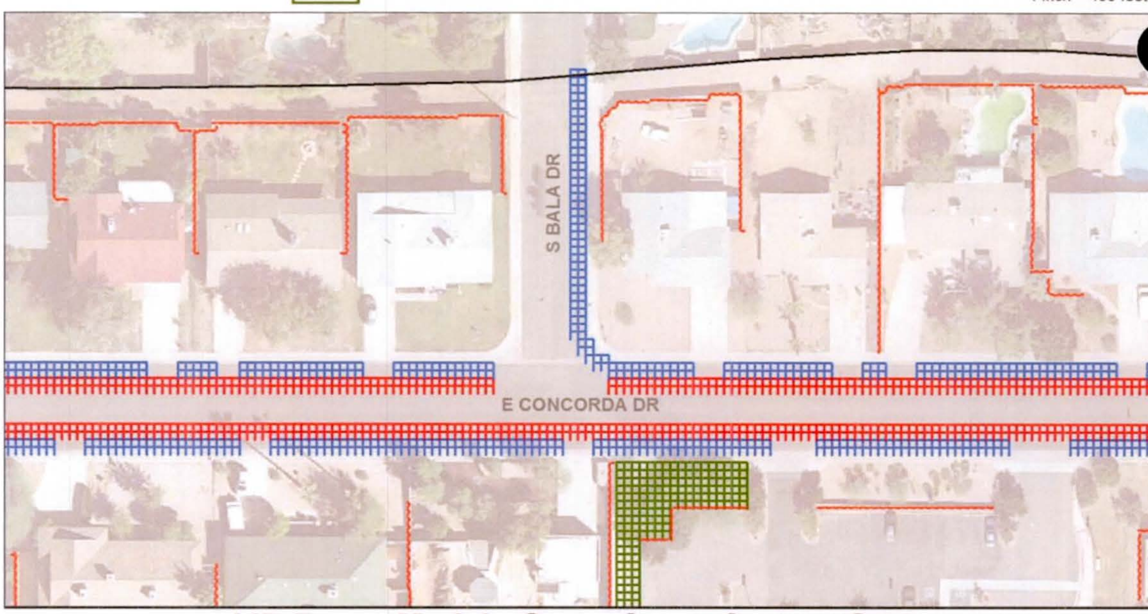


LID Focus Model - Green Street System Grids

Bio Swale — Model Boundary
Pervious Pavement — Walls
Bio Retention

N

1 inch = 400 feet



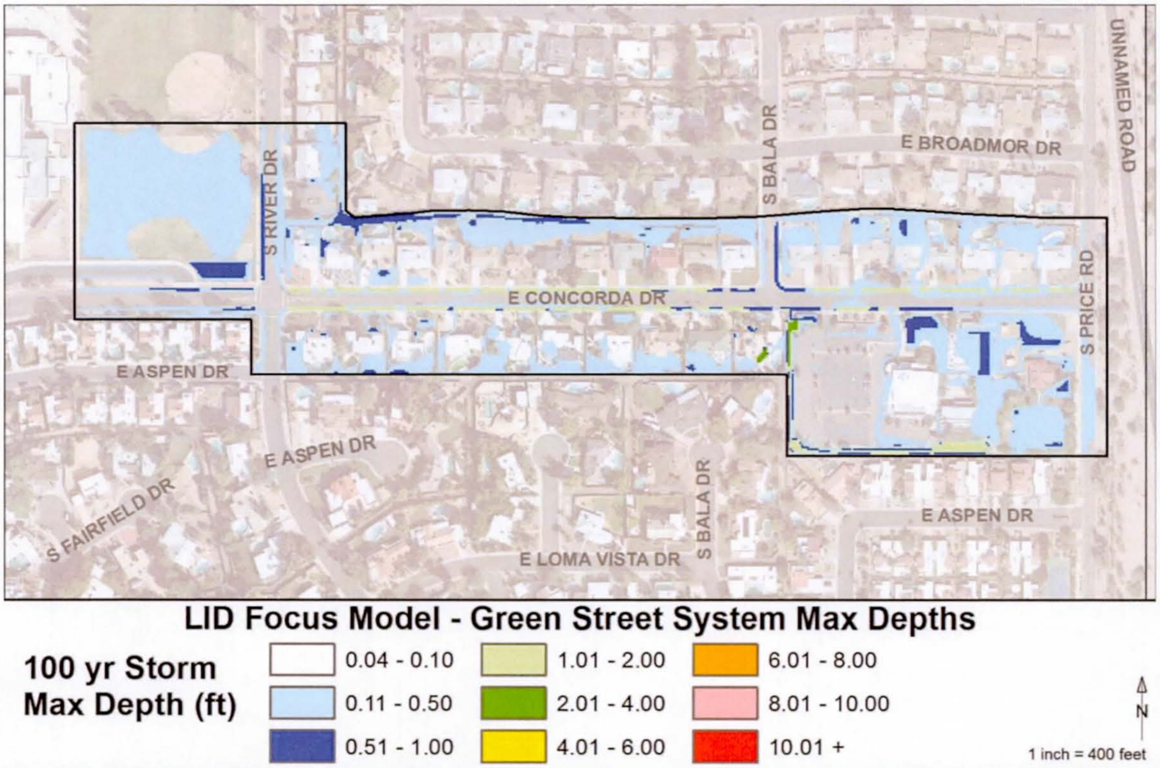
LID Focus Model - Green Street System Grids

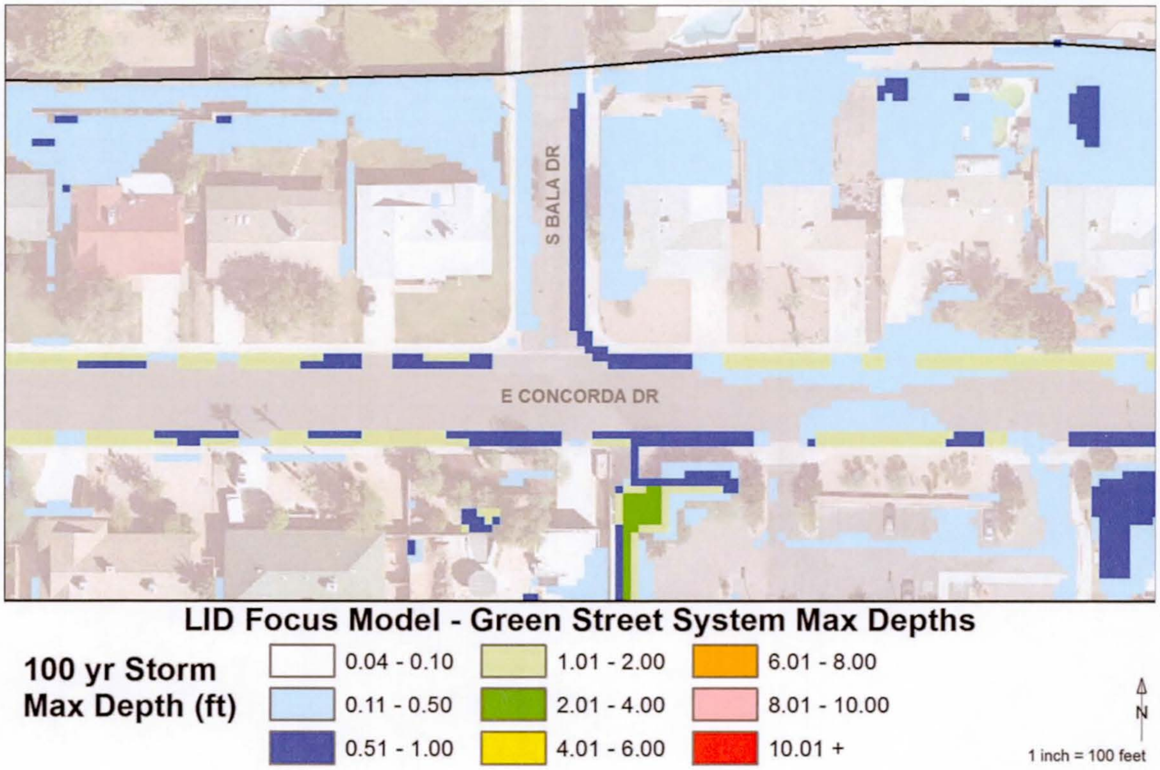
Bio Swale — Model Boundary
Pervious Pavement — Walls
Bio Retention

N

1 inch = 100 feet

The maximum flow depth for the green street area and a close-up area are shown below.





5.5 Summary of Modeling Results for Three LID Control Systems

The FLO-2D modeling results for the base model as well as the three LID systems are summarized in Table 5.1. Table 5.1 shows that Green Street System has the highest utilization of LID design volume (55.2%). The other two systems have similar utilization percentage (~47.5%). Figure 5.1, as an example of the cross section hydrographs, shows that on lot treatment system has the highest peak flow reduction in all three LID systems. The peak flow of 7.9 cfs for the base model at floodplain cross section of Bala Drive is reduced to 1.1 cfs for the on lot treatment LID system, 1.8 cfs for the green parking LID system, and 3.3 cfs for the green street LID system. The on lot treatment LID system has the highest peak flow reduction due to its high LID target (design) volume (3.11 ac-ft, see table 5.1). The modeling results show that all three LID systems are very effective in flood mitigation (reducing the downstream storm water peak flows and volumes).

Table 5.1 Summary Table for LID System Modeling Results						
			Base Model	On-Lot Treatment	Green Parking	Green Street
		Model	LID 2.1	LID 20	LID 21	LID 22
	Target volume capture	V (acft)	-	3.107	1.807	1.830
SWMM RPT	Outflow (Outfall node I338)	Qp (cfs)	8.58	3.17	5.27	2.14
SWMM RPT	Wet weather inflow	V (acft)	1.192	0.146	0.756	0.397
SWMM RPT	Return flow	V (acft)	0.041	0	0.002	0
SUMMARY OUT	Total point rainfall	in	2.52	2.52	2.52	2.52
SUMMARY OUT	Overland infiltration & interception	in	0.88	1.75	1.25	1.36
SUMMARY OUT	Rainfall volume	V (acft)	4.37	4.37	4.37	4.37
SUMMARY OUT	Infiltration & interception	V (acft)	0.93	2.31	1.62	1.79
		%	21	53	37	41
SUMMARY OUT	Floodplain storage	V (acft)	1.47	1.56	1.64	1.62
		%	34	36	38	37
SUMMARY OUT	TOL storage	V (acft)	0.07	0.07	0.07	0.07
		%	2	2	2	2
SUMMARY OUT	Floodplain outflow	V (acft)	0.76	0.36	0.36	0.57
		%	17	8	8	13
SUMMARY OUT	To stormdrain (FLO-2D to SWMM)	V (acft)	1.23	0.14	0.75	0.39
		%	28	3	17	9
SUMMARY OUT	Stormdrain return flow (SWMM to FLO-2D)	V (acft)	0.03	0	0	0
		%	1	0	0	0
Check	Sum of volumes	V (acft)	4.36	4.37	4.37	4.37
Check	Utilization of LID volume	%	-	47.3	47.6	55.2
Storage Additions	Grading	V (ft³)	-	79035	44364	45421
Storage Additions	Initial abstraction	V (ft³)	-	22969	-590	-492
Storage Additions	Increased soil depth	V (ft³)	-	33329	34932	34775
Storage Additions	Sum	V (ft³)	-	135332	78707	79704
		V (acft)	-	3.11	1.81	1.83

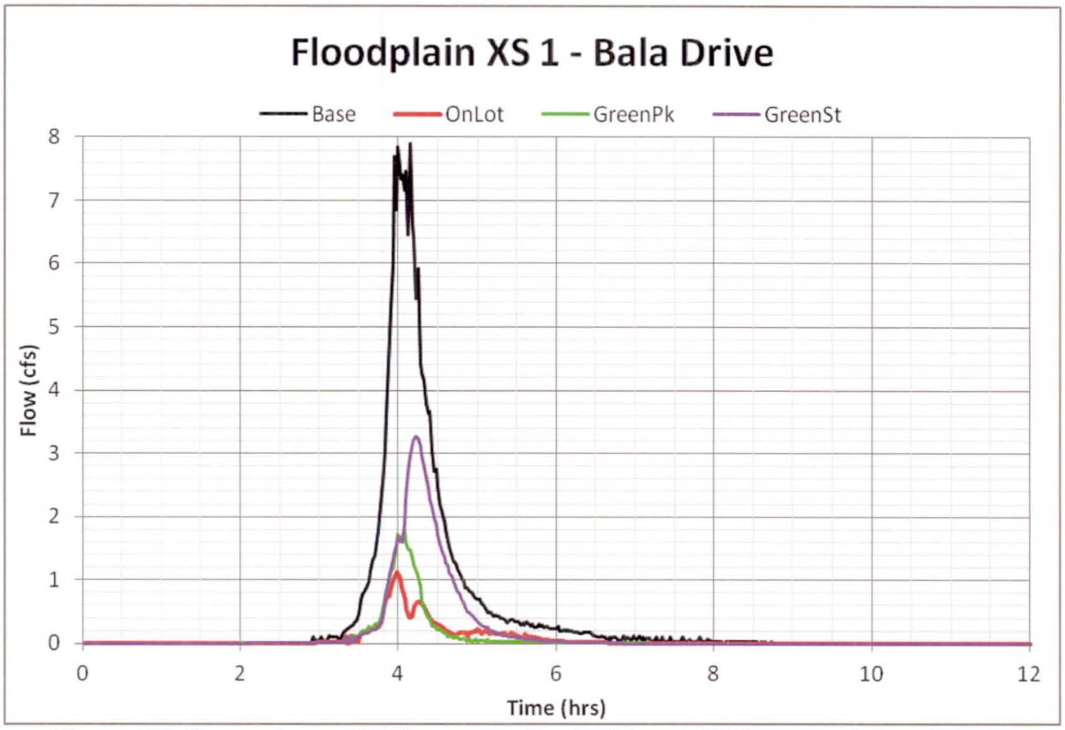


Figure 5.1 Comparison of Hydrographs for the Three LID Systems (example)

6.0 SIMULATION OF LID SCENARIOS BY REGIONAL MODELS

6.1 Identification of Modeling Strategies

One of the goals of the individual basic LID control evaluation is to develop a modeling process that can be incorporated into the regional FLO-2D models. The FLO-2D modeling procedures for individual basic LID controls from the Focus Area model (4 ft x 4 ft grid size) should be adjusted to be applied to regional modeling of LID scenarios. A LID scenario is defined as a LID practice system that includes multiple basic LID controls, accessories, and various land uses with certain parcel participation rate. The Loma Vista FLO-2D model was used for the regional modeling of LID application scenarios. Figure 2.1 shows the Loma Vista FLO-2D modeling boundaries.

The direct impact of LID practices on flood mitigation is the reduction of surface runoff volume to the downstream areas due to the rainfall/runoff responses of many localized LID controls (retention, detention, infiltration, storage and re-use, high surface roughness). A key operational function of the FLO-2D model is the conservation of volume. The model accounts for volume in several ways including: surface storage, surface flow, storm drain flow, and infiltration. The reductions in volume are quantified in the model outflow hydrographs, model output summaries, and from placed floodplain cross sections. One of the advantages in the evaluation of LID scenarios in a regional FLO-2D model is that it is able to accurately depict impacts on a parcel by parcel basis and conservation of volume, though the 20 ft x 20 ft grids may be too coarse of a resolution to model some of the actual physical processes that are occurring at some LID accessories.

Further evaluations concluded that Initial Loss IA Adjustment is the most appropriate method among the potential techniques since this method has the following advantages over other approaches:

a. It is already a distributed parameter (grid dependent) and no new input data file is needed;
b. It is easy to be estimated and directly related to runoff volume and depth;
c. Changes of IA values represent best the basic LID control impact on hydrologic and hydraulic performance, such as rainfall/runoff timing and spatial variations;
d. It is a physical hydrologic parameter;
e. It can be used for all of the five basic LID controls.

Other methods do not have all of the advantages. For example, Grid Elevation Adjustment method does not work very well for variations of grid elevations (runoff may not be able to flow into the LID areas). TOL method has significant impact on hydraulic computations. Therefore, Initial Loss IA Adjustment was recommended for the modeling of LID scenarios in the regional modeling.

Detailed procedures for parameter adjustment from basic LID control modeling processes for simulation of LID scenarios are discussed in the following sections.

6.2 Estimation of LID Design Capacities for Various Land Uses

All the parcels within the modeling area are classified based on land use zoning provided by the City. For this example modeling, eight (8) zoning numbers were used, but streets are not parcel-based. Each parcel-based land use zoning was evaluated by using the following spreadsheet to estimate the composite design LID volume capability (V_d). Spreadsheets for the seven (7) parcel-based land uses were included in Appendix G1. The composite capacity for each land use is estimated based on the five basic LID controls modeling results as well as the utilization effectiveness which is a correction factor with value less than 1.0 for individual LID controls. The utilization effectiveness factor for each of the five basic LID controls obtained from the Focus Area modeling is a very important parameter in the determination of the LID modeling volumes. The 100-year, 2-hour storm rainfall volume (V_2) was assumed to be the maximum LID design volume for a parcel. If the possibly constructed LID volume (Vc) for a parcel is greater than the 100-year, 2-hour storm volume, the utilization effectiveness factor (U_e) was applied ($V_d = V_2/ U_e <= V_c$). If the possibly constructed LID volume (Vc) for a parcel is less than or equal to the 100-year, 2-hour storm volume, the utilization effectiveness factor (U_e) was not applied and the design volume is the same as the 100-year, 2-hour storm volume ($V_d = V_2$) where V_d is the composite LID design volume and the FLO-2D LID modeling volume.

Street LID design capacities greatly depend on the functional classification of the roadway. Minor residential streets do not have as much right-of-way, which limits LID opportunities generally to small bio swales and pervious pavement. As the functional classification goes up towards arterials, bio swales can be more prominent while pervious pavement becomes less viable. The LID Design Capacity for streets is defined in cubic feet per lineal foot. Estimates of these capacities were obtained based on the applicability of LID applications on Country Club Way and Concorda Drive as shown in Exhibit C0.

The estimated composite design capacities for the eight (8) zooming numbers are listed in Table 6.1. These values for each parcel can be refined or revised based on real project area land use conditions and other factors. The values utilized for the Loma Vista model have been quantified through the Focus Area modeling efforts. In addition, the proposed procedure allows the modeler to easily refine the values to be utilized if modifications are required.

Table 6.1 Land Use Zoning and LID Design Capacities

Land Use Zoning No.	LID Land Use		LID Design Capacity	
	Zoning Name	Description	Value	Unit
1	AG	Parks & Golf Course	3500	ft^3/ac
2	CSS	Commercial	6000	ft^3/ac
3	R-2	Adjoined homes/duplexes	500	ft^3
4	R-3	Apartments	4000	ft^3/ac
5	R1-6	Medium-lot homes	1000	ft^3
6	RO	Church	5000	ft^3/ac
7	MU-2	School	4500	ft^3/ac
8	ST	Street	5-30	ft^3/lf

	Design Capacity Estimation for Individual Lot LID Controls	By:	**JJH**
		Date:	**1/18/16**
Project Name:	**Tempe ADMS - FLO-2D Modeling of LID Applications**	Checked:	
		Project No.:	**130.622**

Reference: Drainage Design Manual for Maricopa County, Arizona, Vol. 1, Hydrology

INPUT:

Rainfall

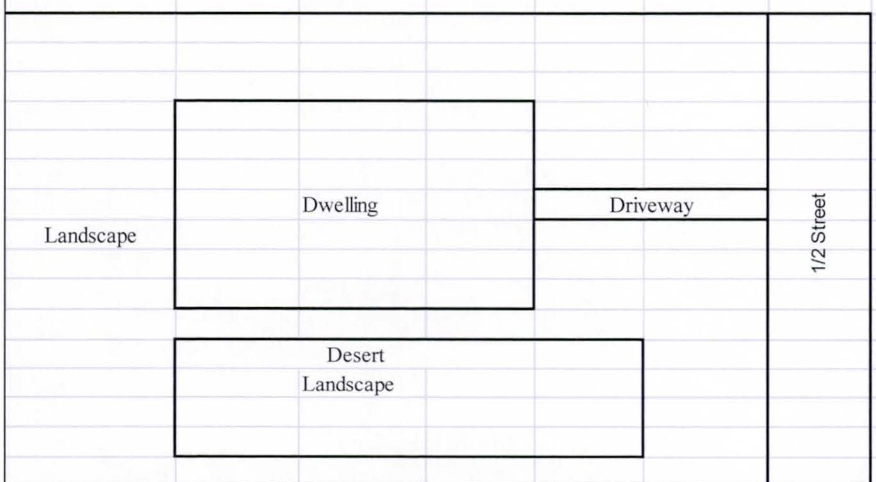
Return Interval = 100-year 2-hour = 2.16 inches = 0.180 ft

Criteria Equations

Volume, V = C * P* A (C = runoff coefficient, P = precipitation, A area)

Zoning = R1-6
Lot Size = 8250 square feet
0.19 acres

Landuse	Area (Sq. ft.)	C	C*A
Structure Size	3766	0.95	3578
1/2 Street (w = 20 ft, and assume 2 sides of lot adjacent to road)	0	0.95	0
Desert Landscaping	3884	0.50	1942
Landscaping	0	0.35	0
Driveway	600	0.95	570
Total	8250	0.74	6089.70 OK



Lot Size = 0.189 Acres

Runoff Volume Generated by Lot = 0.025 Acre-ft
1096 cu ft

Low Impact Development (LID) Controls

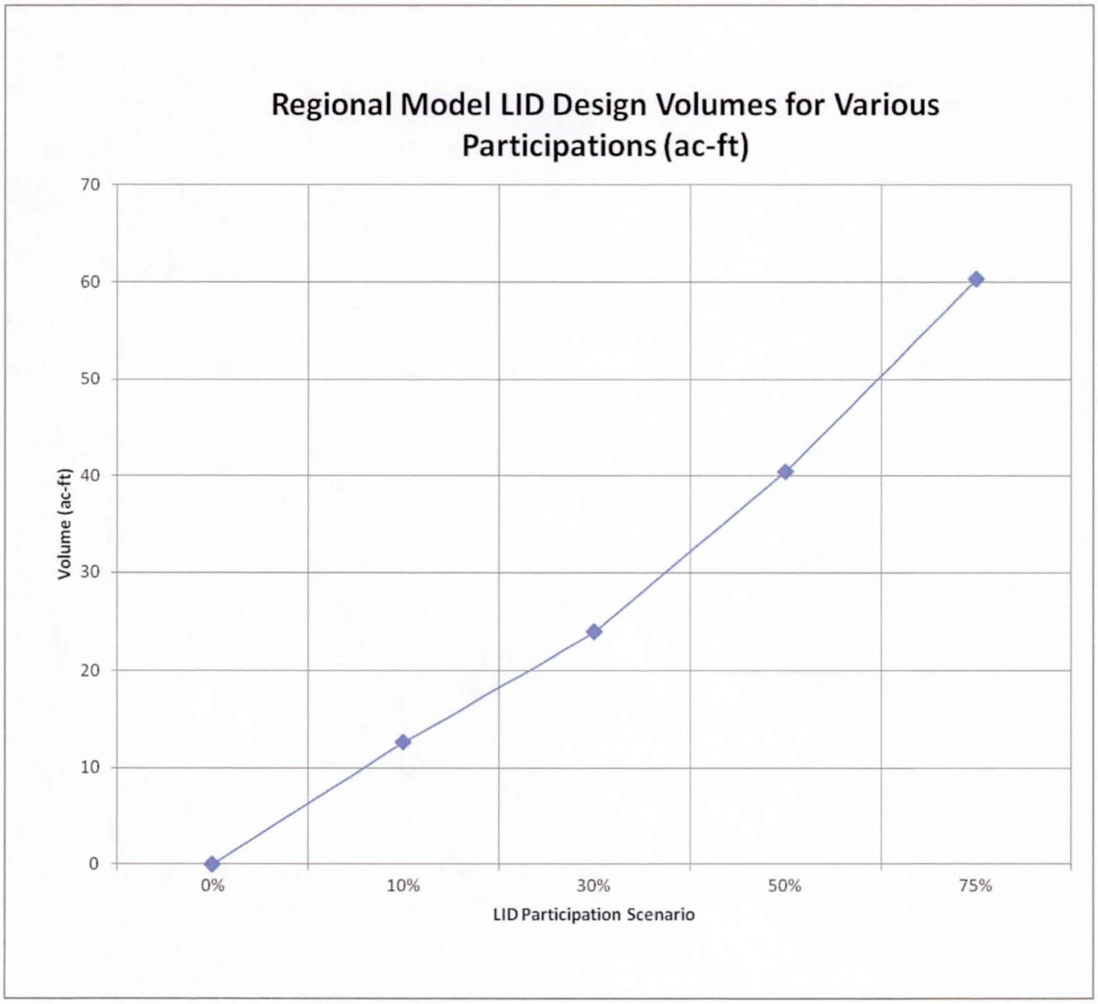
Bio Retention	652	cu ft
Bio Swale	0	cu ft
Pervious Pavement	240	cu ft
Rainwater Harvesting	100	cu ft
Green Roof	0	cu ft
Total LID Volume	992	cu ft
Green Roof		
Portion of Roof Contained =	0.00	
Contributing Roof Area =	0	sq ft
Roof Volume =	0	cu ft
Rainwater Harvesting		
Portion of Roof Contained =	0.50	
Contributing Roof Area =	1883	sq ft
Roof Vol. Contributing to Tank =	339	cu ft
Rain Tank Volume =	100	cu ft
Controlling Volume =	100	cu ft
Bio Retention		
bottom length	30.00	ft
bottom width	10.00	ft
Depth	1.00	ft
Side Slope	4.00	ft/ft
Top Length	38	ft
Top Width	18	ft
Stored Volume	481	cu ft
Stored Volume	0.01	ac-ft
Infiltration Rate	1.00	in/hr
Duration	6.00	hr
Additional Limiting Depth	3.00	
Infiltration Volume	171	cu ft
Bio Swale		
bottom length	0.00	ft
bottom width	0.00	ft
Depth	0.00	ft
Side Slope	0.00	ft/ft
Top Length	0	ft
Top Width	0	ft
Stored Volume	0	cu ft
Stored Volume	0.00	ac-ft
Infiltration Rate	0.00	in/hr
Duration	0.00	hr
Infiltration Volume	0	cu ft
Pervious pavement		
Area	600	sq ft
Volume	240	cu ft

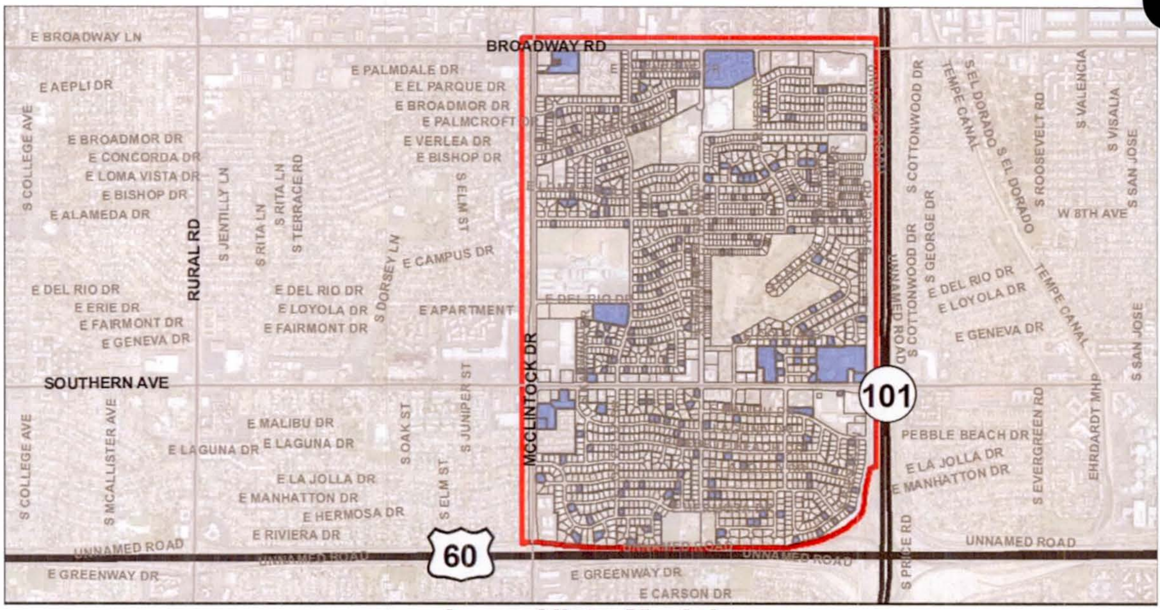
6.3 Determination of LID Application Scenarios

A LID scenario is defined as a LID practice system that includes multiple basic LID controls, accessories, and various land uses with certain parcel participation rate. Different LID application scenarios can be developed by combining several LID controls and storm drain system may be added to enhance the performance of the LID practices. Since the number of scenarios is numerous four (4) LID application scenarios were selected for this study to demonstrate the FLO-2D modeling techniques and the effectiveness of LID applications on flood mitigation:

1) Scenario I: 10% parcel participation rate;
2) Scenario II: 30% parcel participation rate;
3) Scenario III: 50% parcel participation rate;
4) Scenario IV: 75% parcel participation rate.

Parcels were randomly assigned to be used for each scenario as shown in the following maps (see Appendix E2 D also). The estimated LID design volumes for the four (4) proposed participation scenarios are shown in the following chart. These values were applied in the development of FLO-2D input data files.

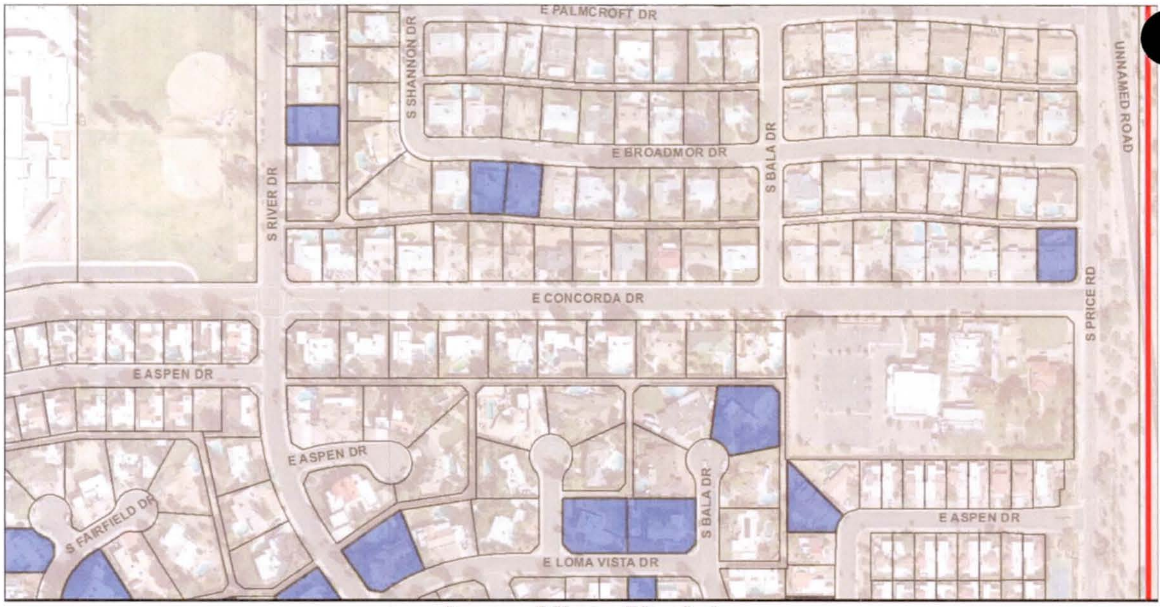




Loma Vista Model
10% LID Participation Parcels

Parcels
Model Boundary
Participating Parcels

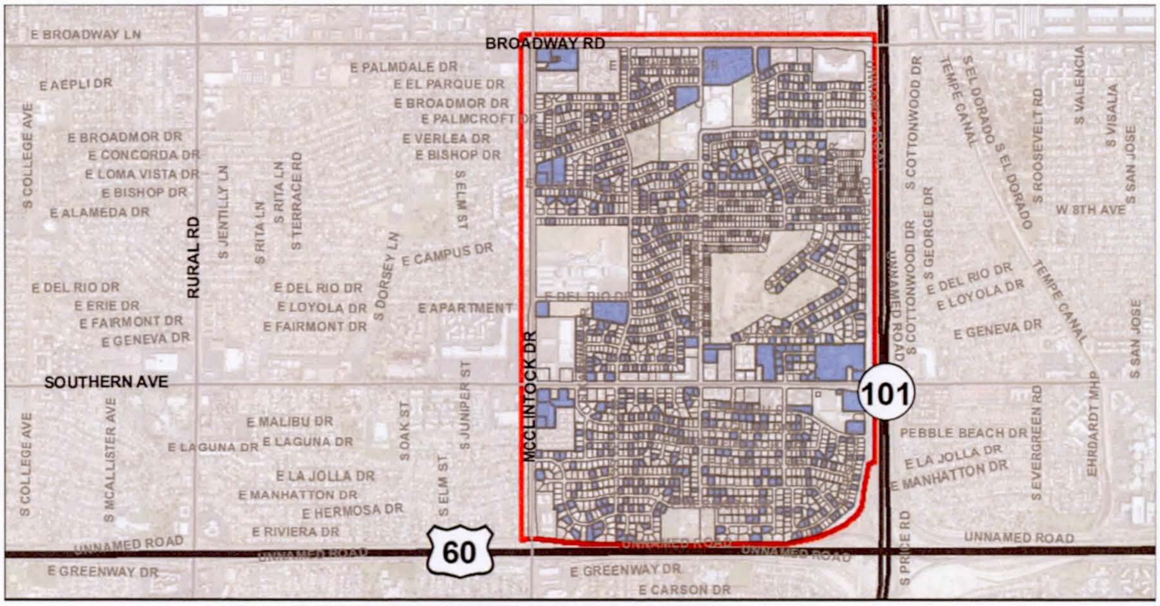
N
1 inch = 3,000 feet



Loma Vista Model
10% LID Participation Parcels

Parcels
Model Boundary
Participating Parcels

N
1 inch = 400 feet



Loma Vista Model
30% LID Participation Parcels

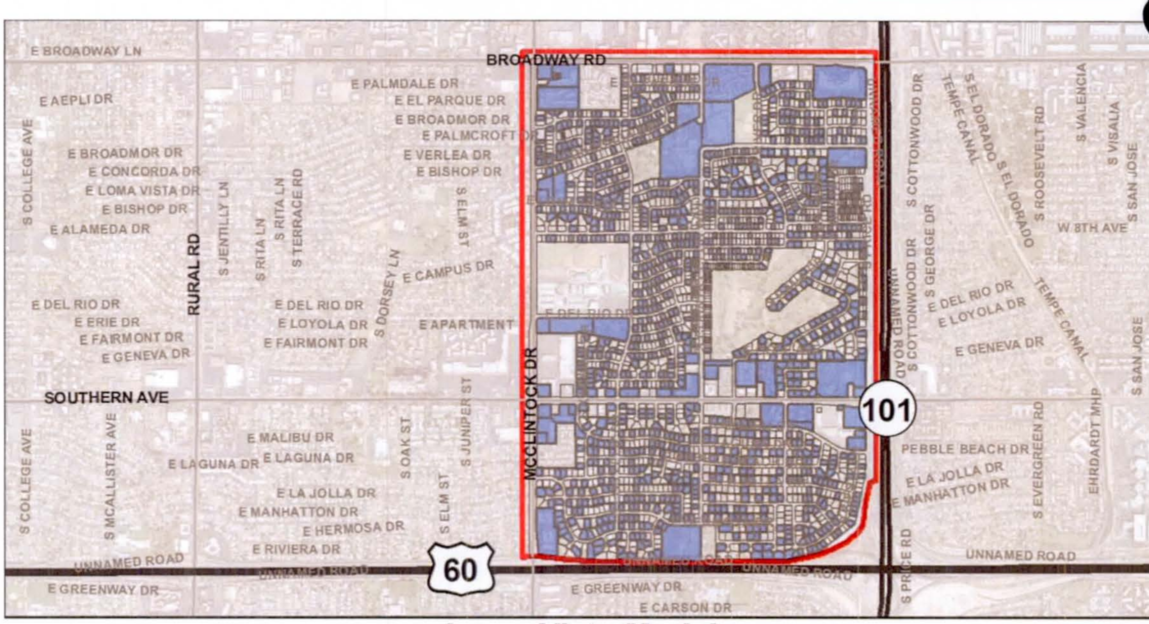
Parcels | Model Boundary
Participating Parcels

N
1 inch = 3,000 feet

Loma Vista Model
30% LID Participation Parcels

Parcels | Model Boundary
Participating Parcels

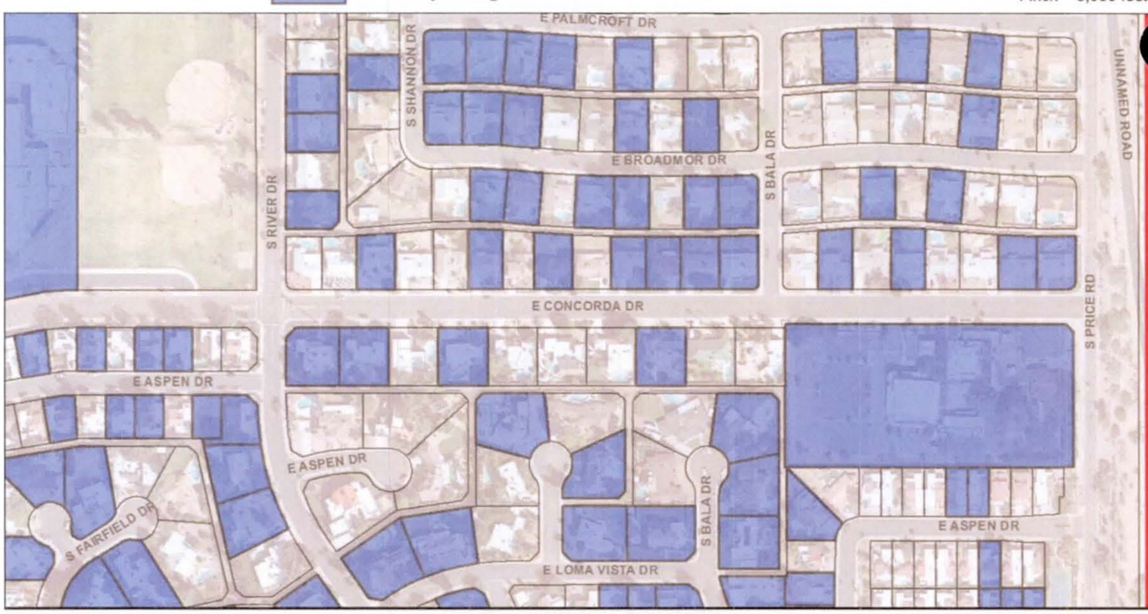
N
1 inch = 400 feet



Loma Vista Model
50% LID Participation Parcels

Parcels
Model Boundary
Participating Parcels

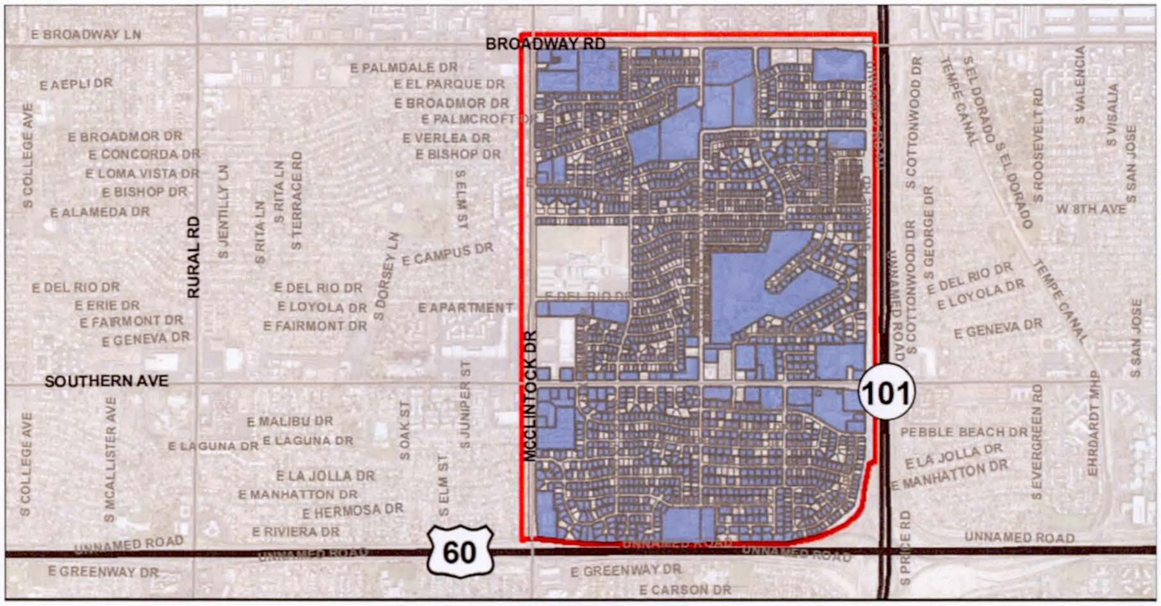
N
1 inch = 3,000 feet



Loma Vista Model
50% LID Participation Parcels

Parcels
Model Boundary
Participating Parcels

N
1 inch = 400 feet



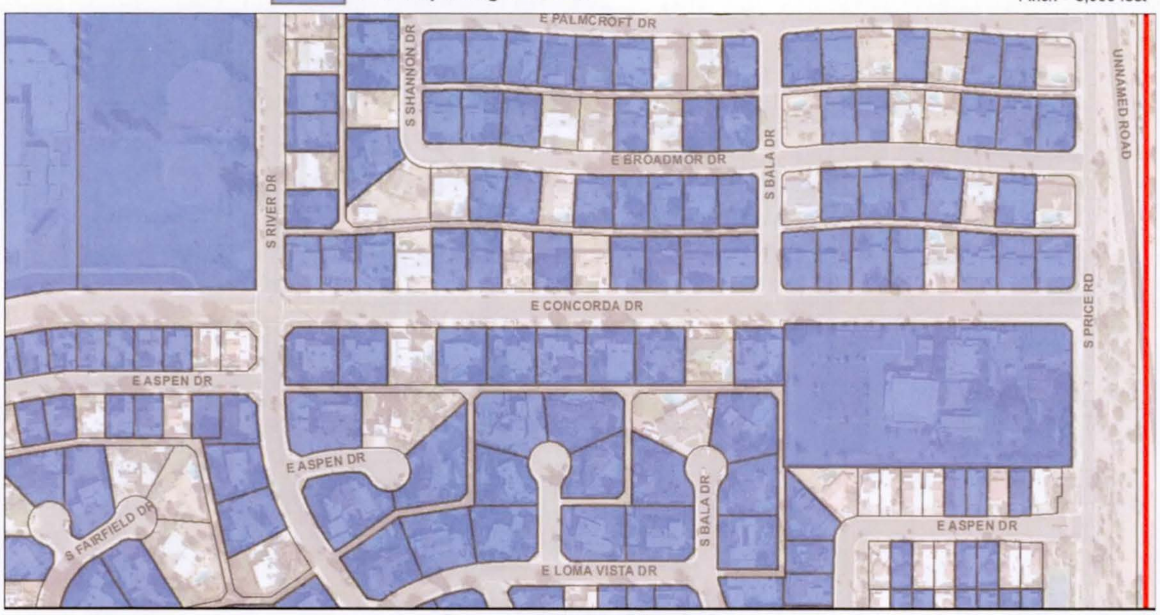
Loma Vista Model
75% LID Participation Parcels

Parcels | Model Boundary

Participating Parcels

N

1 inch = 3,000 feet



Loma Vista Model
75% LID Participation Parcels

Parcels | Model Boundary

Participating Parcels

N

1 inch = 400 feet

6.4 Development of FLO-2D Input Data Files

The specific steps for the development of INFIL.DAT are as follows:

1) Create a new shapefile consisting parcels only;
2) Remove parcels with area below minimum criteria (Example: 100 ft^2);
3) Classify parcels by zoning numbers in terms of LID volume capabilities;
4) Calculate a parcel zoning-specific IA adjustment based on the classified volume and the parcel contributing area (A), added IA = Vol/A;
5) Determine scenarios for participation levels by percent of parcels. For example: 10% parcels participate in LID scenario 1, 30% in scenario 2, 50% in scenario 3, and 75% in scenario 4. Randomly assign which parcels to use for each scenario (see Exhibit D);
6) Create rasters (4 ft resolution or smaller) using selected parcels for each scenario based on the IA adjustment values;
7) Associate IA adjustment values to grid number shapefile using Manifold;
8) Add IA adjustment values to original IA values and create new INFIL.DAT file.

Five (5) FLO-2D models were developed and executed for the base model and the four (4) LID scenarios. The base model is the model with 0% LID participation. The FLO-2D model input and output files and modeling results are included in Appendix E.

6.5 Evaluation of FLO-2D Modeling Results for LID Scenarios

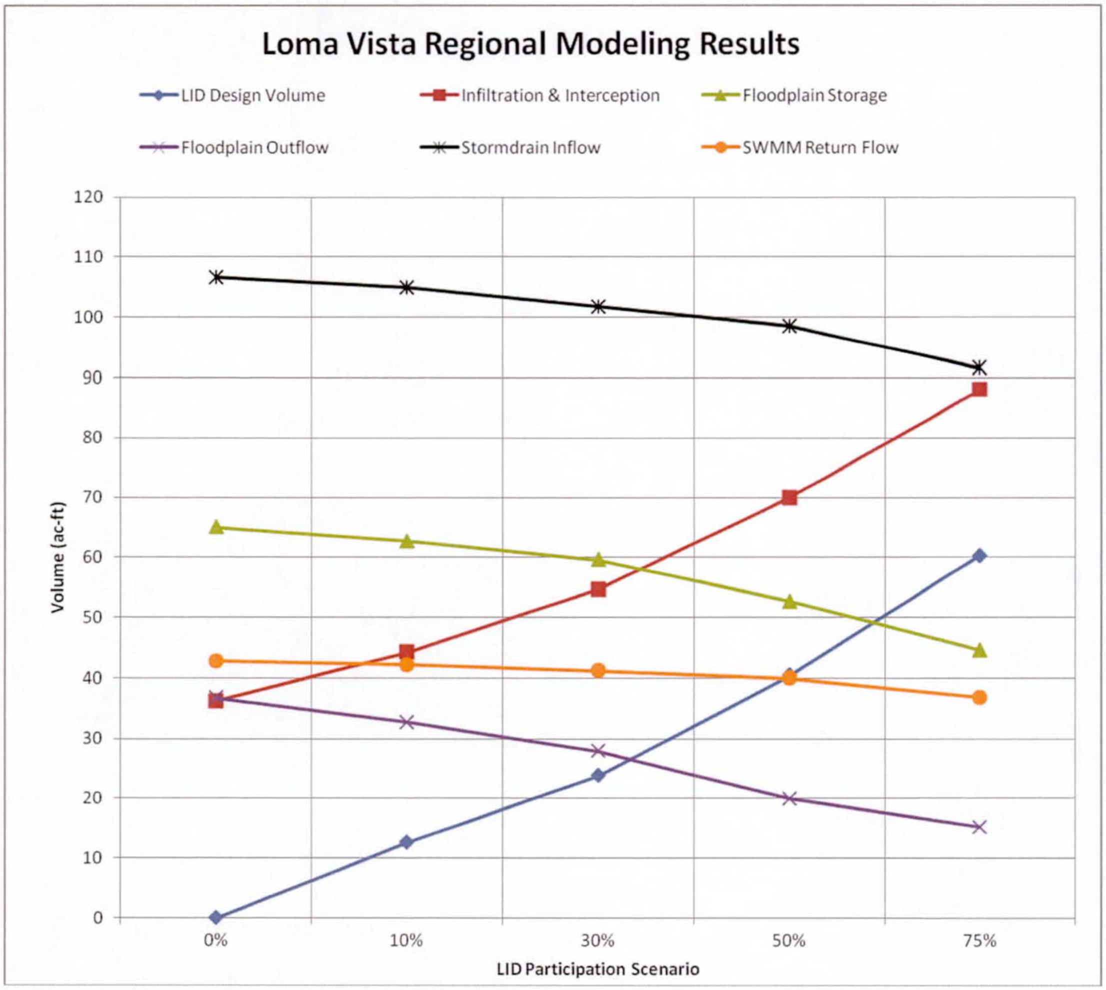
The recommended FLO-2D modeling techniques and LID applications were incorporated into Loma Vista model to quantify the impact of LID on storm water runoff. The Loma Vista FLO-2D model was developed for possible evaluation of various LID systems and scenarios within the project area and can serve as a preliminary approach for developing LID CIP projects within the Tempe ADMS watersheds. The final design will require development and refinement of more detailed LID alternatives. Hopefully, this project will allow LID to become one of the mainstream flood control measures in urbanized watersheds.

The FLO-2D/SWMM modeling results for the regional model (Loma Vista Area) and four (4) LID participation scenarios are summarized in Table 6.2 and the following charts.

Table 6.2 Loma Vista Regional Modeling Results

Participation Rate	LID Design Volume	Infiltration & Interception	Floodplain Storage	Floodplain Outflow	Stormdrain Inflow	SWMM Return Flow	SWMM Total Outflow
	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)
0%	0.0	36.3	65.0	36.8	106.7	42.8	100.1
10%	12.6	44.2	62.7	32.8	105.0	42.1	98.3
30%	23.8	54.7	59.6	28.0	101.7	41.2	95.3
50%	40.4	70.0	52.6	19.9	98.6	40.0	90.8
75%	60.3	88.0	44.6	15.2	91.5	36.8	84.4

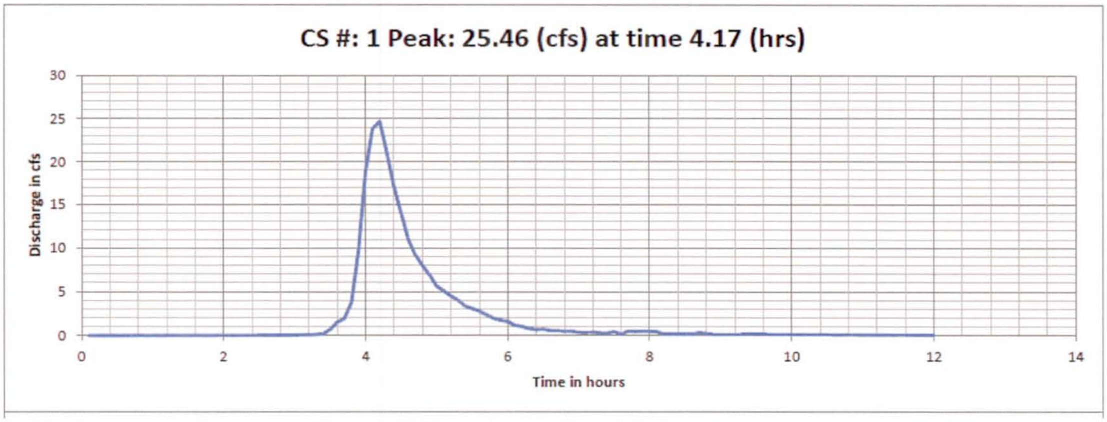
The LID design volume and FLO-2D reported watershed infiltration & interception volume increase with the increase of the LID participation rate as expected. Floodplain (watershed) storage, surface outflow, storm drain inflow, storm drain outflow, and storm drain return flow (flooding) decrease with the increase o the LID participation rate. The reduction of storm drain return flows is not very significant due to the small storm drain capacity compared to the 100-year storm runoff. The following charts show these patterns.



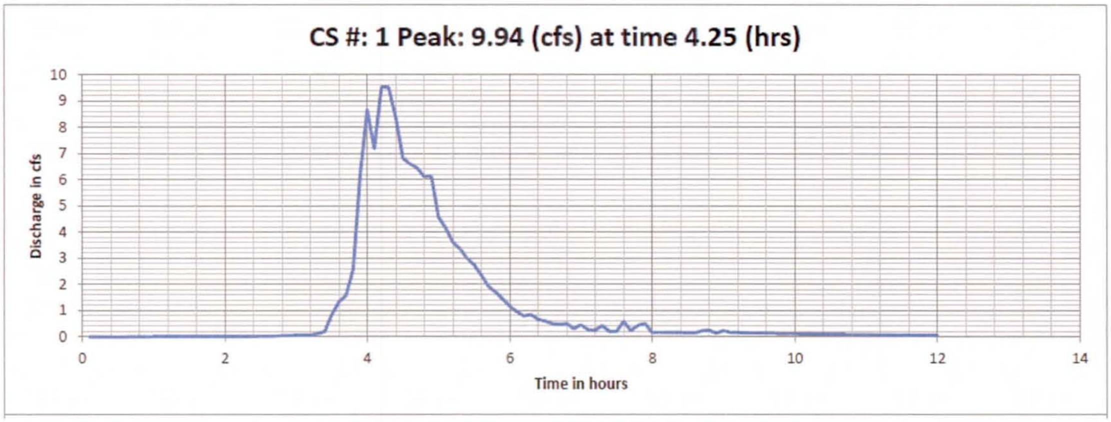
In order to show the effectiveness of LID applications on the surface peak flow reduction surface flow hydrographs at two of the floodplain cross sections at the downstream of the modeling area were shown in the following charts (all cross section (CS) hydrographs are included in Appendix E4):

CS #1 is located at McClintock Dr. and Broadway Rd and the peak flow is reduced from 25.5 cfs to 9.9 cfs (61% reduction) for the 50% LID participation rate. The time to peak is also delayed from 4.17 hours to 4.25 hours which has some effects on the peak flows at the downstream reaches.

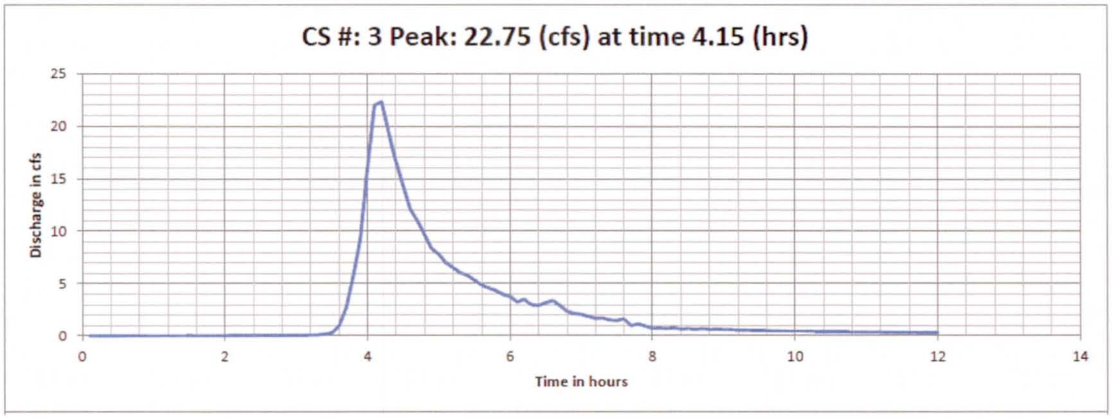
CS #3 is located at Broadway Rd. and McClintock Dr. and the peak flow is reduced from 22.8 cfs to 15.8 cfs (31% reduction) for the 50% LID participation rate. The time to peak is also delayed from 4.15 hours to 4.36 hours which has some effects on the peak flows at the downstream reaches.



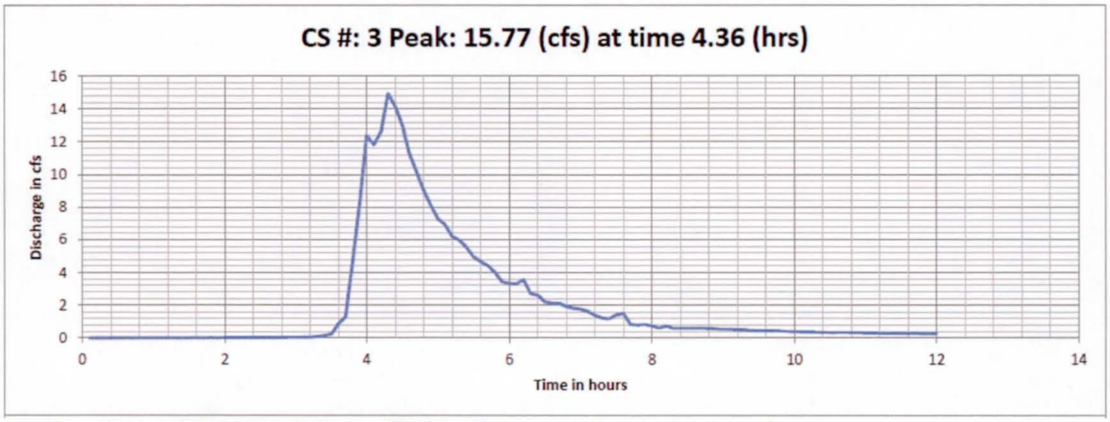
McClintock Dr. at Broadway Rd. - 100-Year Storm, Base Model



McClintock Dr. at Broadway Rd. - 100-Year Storm, 50% LID Participation

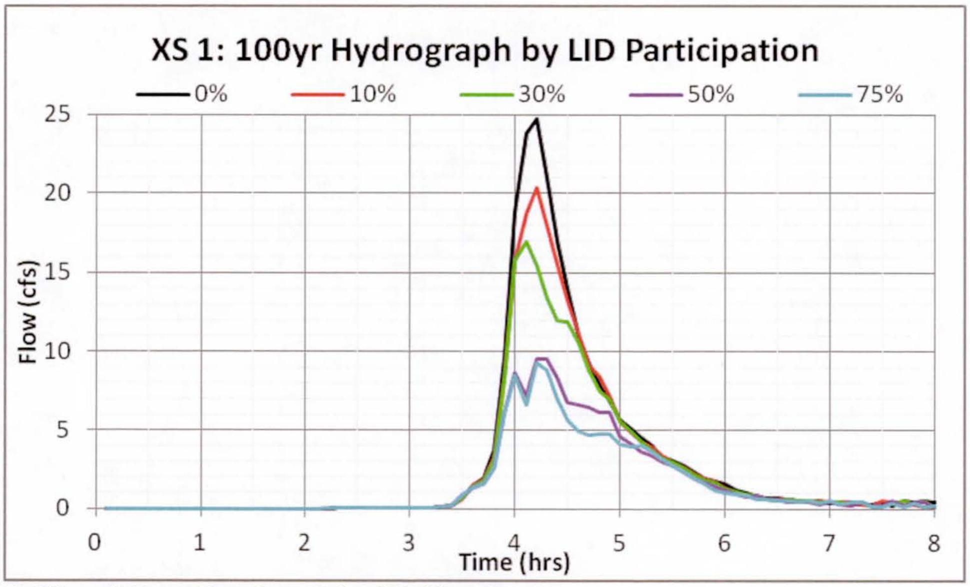


Broadway Rd. at McClintock Dr. - 100-Year Storm, Base Model

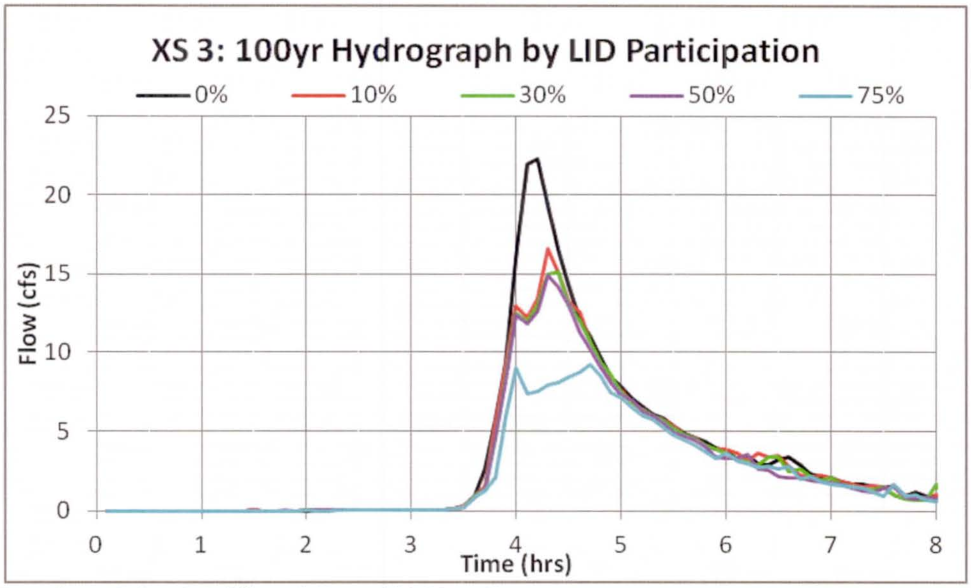


Broadway Rd. at McClintock Dr. - 100-Year Storm, 50% LID Participation

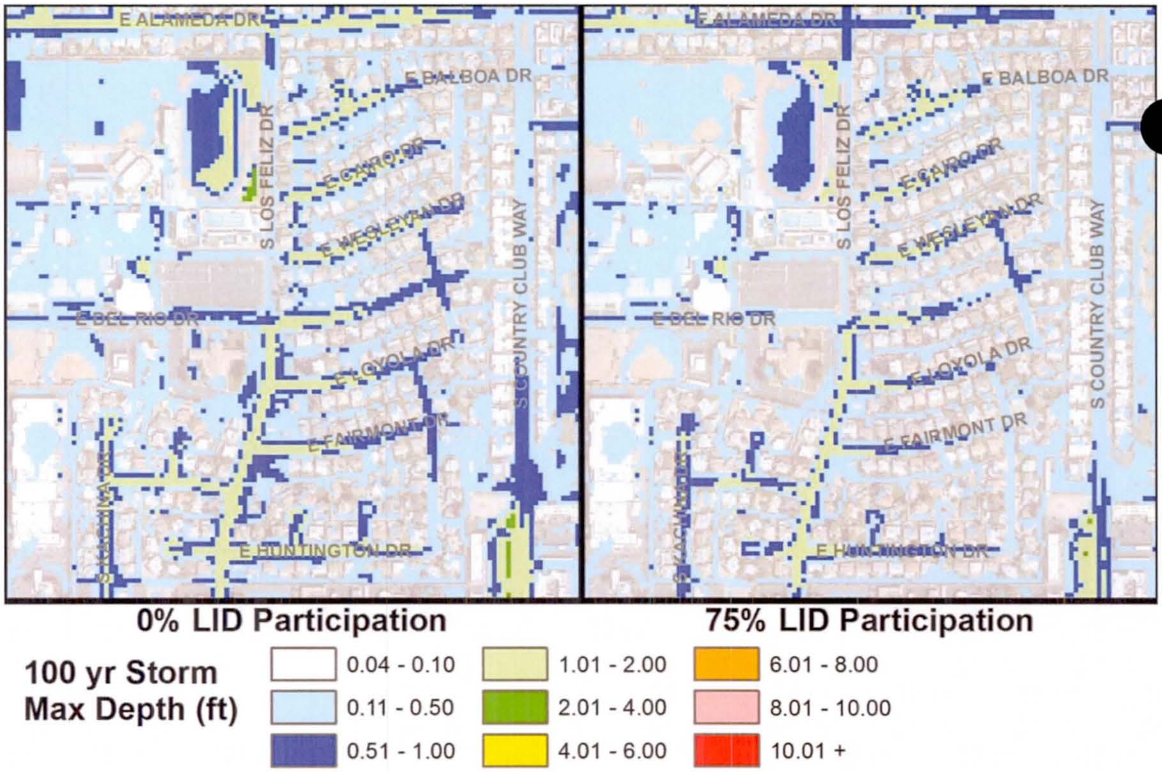
In order to show the impact of LID participation rate on the surface peak flow reduction surface flow hydrographs at two of the floodplain cross sections at the downstream of the modeling area were shown in the following charts with all of the four (4) LID participation rates. These two charts show that surface runoff reduction increases with the increase of LID participation rate as expected.



McClintock Dr. at Broadway Rd. - 100-Year Storm



Broadway Rd. at McClintock Dr. - 100-Year Storm



McClintock High: Comparison of maximum depths between 0% and 75% LID participation scenarios

7.0 LID IMPLEMENTATION IMPACT ON FLOOD MITIGATION

The impact of LID practices on flood mitigation depends on many factors, such as LID composite design capacity (individual LID sizes), LID parcel participation rate (community participation rate – total LID sizes), and storm event frequency (flooding potential/risk).

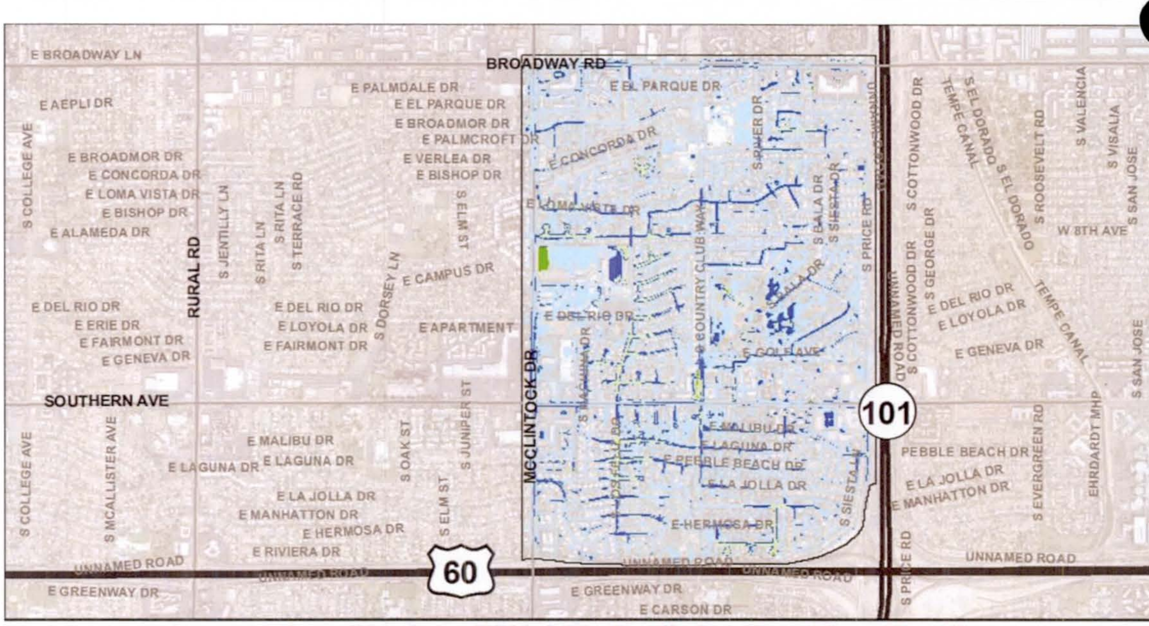
The impact of LID composite design capacity (individual LID sizes) and LID participation scenarios (community participation rate – total LID sizes) on flood mitigation was evaluated in previous section. Theoretically, the larger the LID design capacity and LID participation rate are, the more significant of the impact on flood mitigation is due to LID applications.

Multiple frequency modeling (2-yr, 10-yr, 25-yr, and 100-yr design storms) was conducted to evaluate the LID application effectiveness on flood mitigation for given design LID scenarios using Loma Vista FLO-2D models in the following sub-sections. The four (4) LID application scenarios were evaluated for each of the four (4) storm events to demonstrate the effectiveness of LID applications on flood mitigation for various sizes of storm events:

- Scenario I: 10% parcel participation rate;
- Scenario II: 30% parcel participation rate;
- Scenario III: 50% parcel participation rate;
- Scenario IV: 75% parcel participation rate.

7.1 100-Year Storm Event

The 100-year storm FLO-2D modeling results for the five (5) models were documented in Appendix E and Exhibit D including the base model and the four (4) LID scenarios. The FLO-2D model input and output files and modeling results are included in Appendices E3 and E4. Evaluation of the modeling results was documented in Section 6.5. The following map showed the 50% participation rate. The modeling results for CR #1 and CS #3 show that surface runoff reduction increases with the increase of LID participation rate.



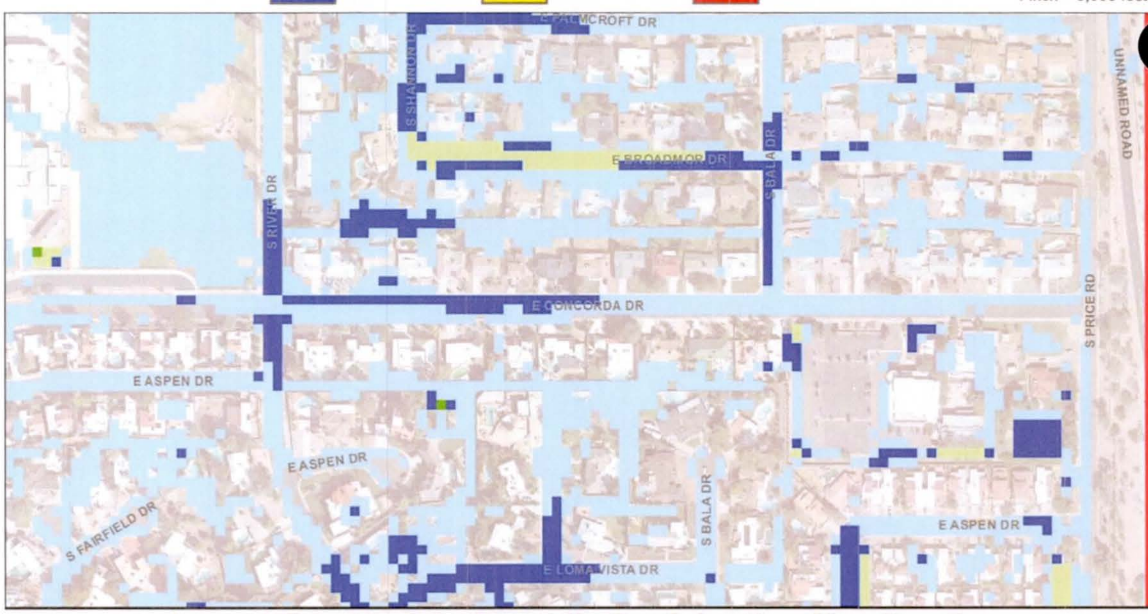
Loma Vista Model - 50% LID Participation Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 3,000 feet



Loma Vista Model - 50% LID Participation Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

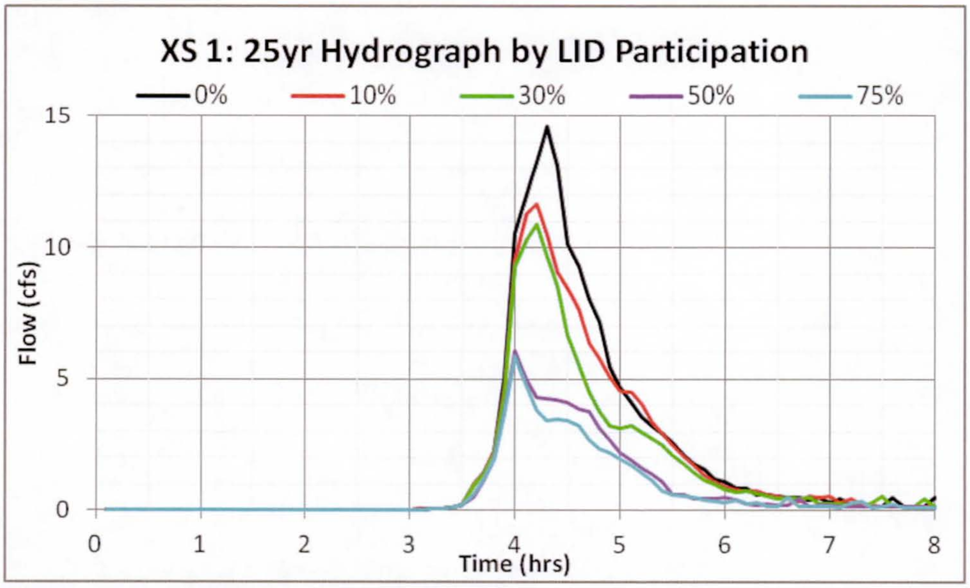
N

1 inch = 400 feet

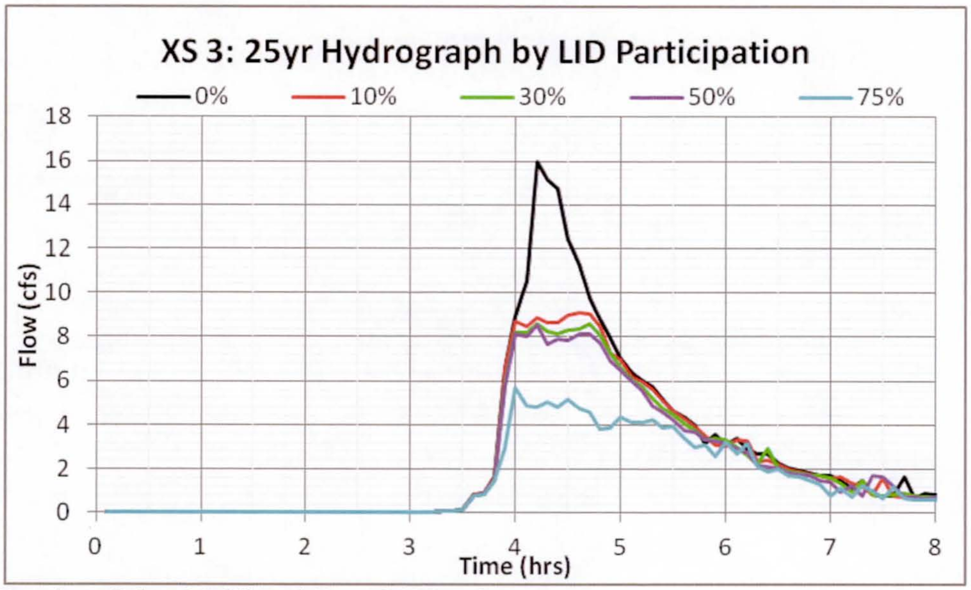
7.2 25-Year Storm Event

The 25-year storm FLO-2D modeling results for the four (5) models were documented in Appendix F and Exhibit E including the base model and the four (4) LID scenarios. The FLO-2D model input and output files and modeling results are included in Appendix F.

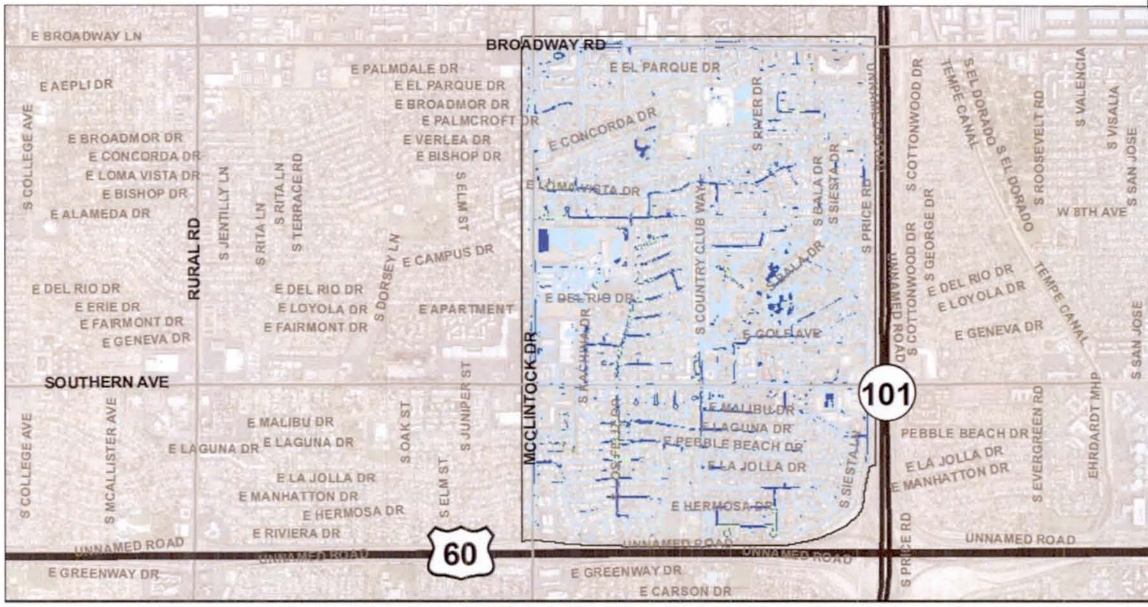
In order to show the impact of LID participation rate on the surface peak flow reduction for the 25-year storm event surface flow hydrographs at two of the floodplain cross sections at the downstream of the modeling area were shown in the following charts with all four (4) LID participation rates. These two charts show that surface runoff reduction increases with the increase of LID participation rate.



McClintock Dr. at Broadway Rd. - 25-Year Storm



Broadway Rd. at McClintock Dr. – 25-Year Storm



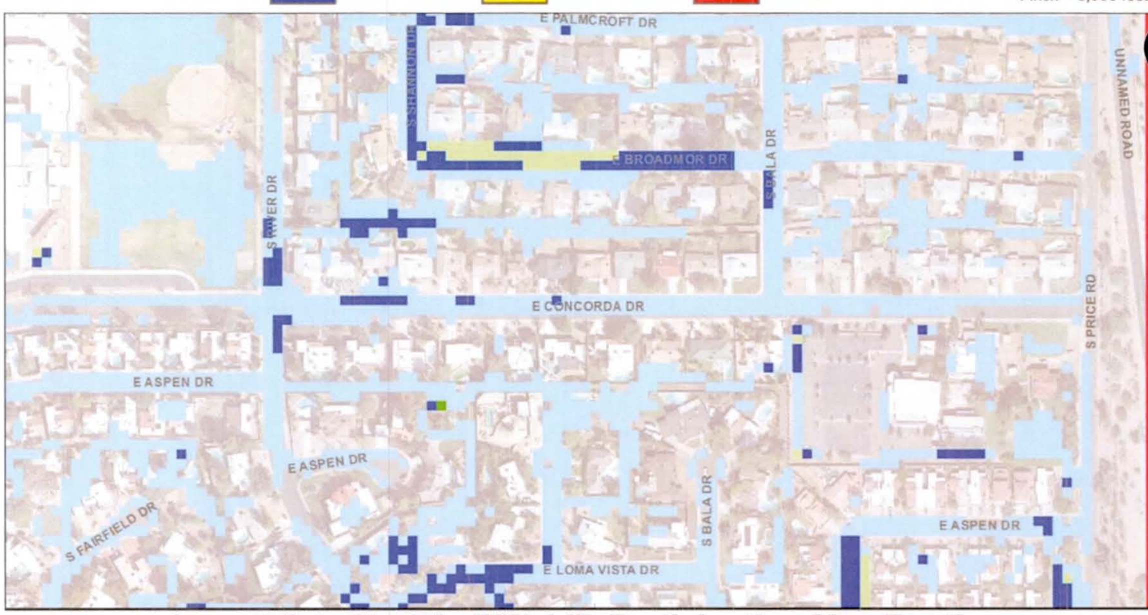
Loma Vista Model - 50% LID Participation Max Depths

25 yr Storm Max Depth (ft)

- 0.04 - 0.10
- 0.11 - 0.50
- 0.51 - 1.00
- 1.01 - 2.00
- 2.01 - 4.00
- 4.01 - 6.00
- 6.01 - 8.00
- 8.01 - 10.00
- 10.01 +

N

1 inch = 3,000 feet



Loma Vista Model - 50% LID Participation Max Depths

25 yr Storm Max Depth (ft)

- 0.04 - 0.10
- 0.11 - 0.50
- 0.51 - 1.00
- 1.01 - 2.00
- 2.01 - 4.00
- 4.01 - 6.00
- 6.01 - 8.00
- 8.01 - 10.00
- 10.01 +

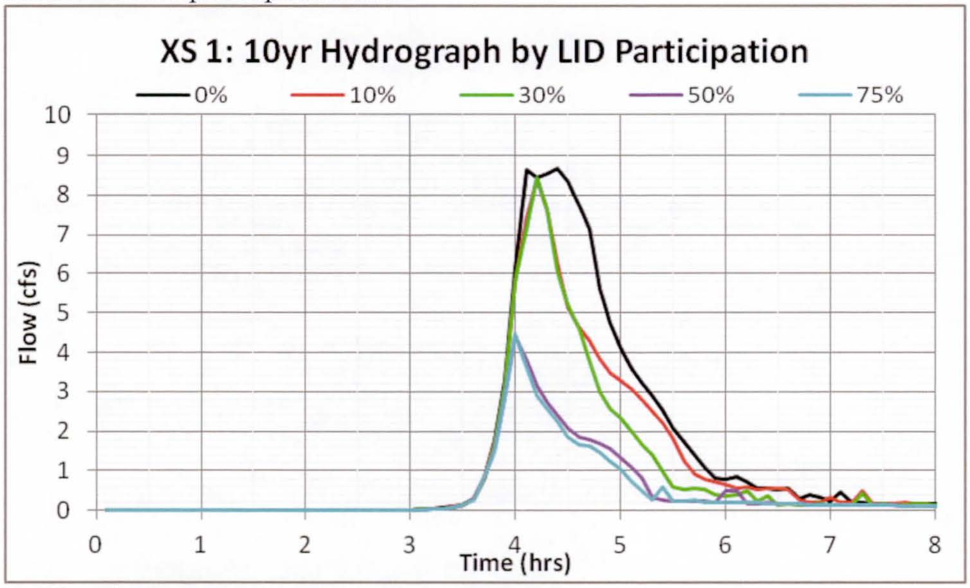
N

1 inch = 400 feet

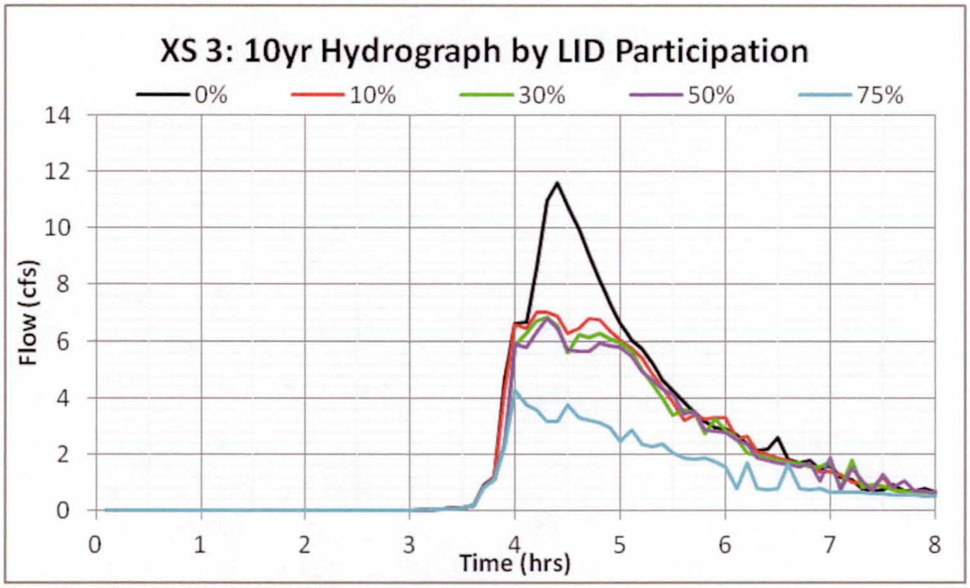
7.3 10-Year Storm Event

The 10-year storm FLO-2D modeling results for the four (5) models were documented in Appendix F and Exhibit E including the base model and the four (4) LID scenarios. The FLO-2D model input and output files and modeling results are included in Appendix F.

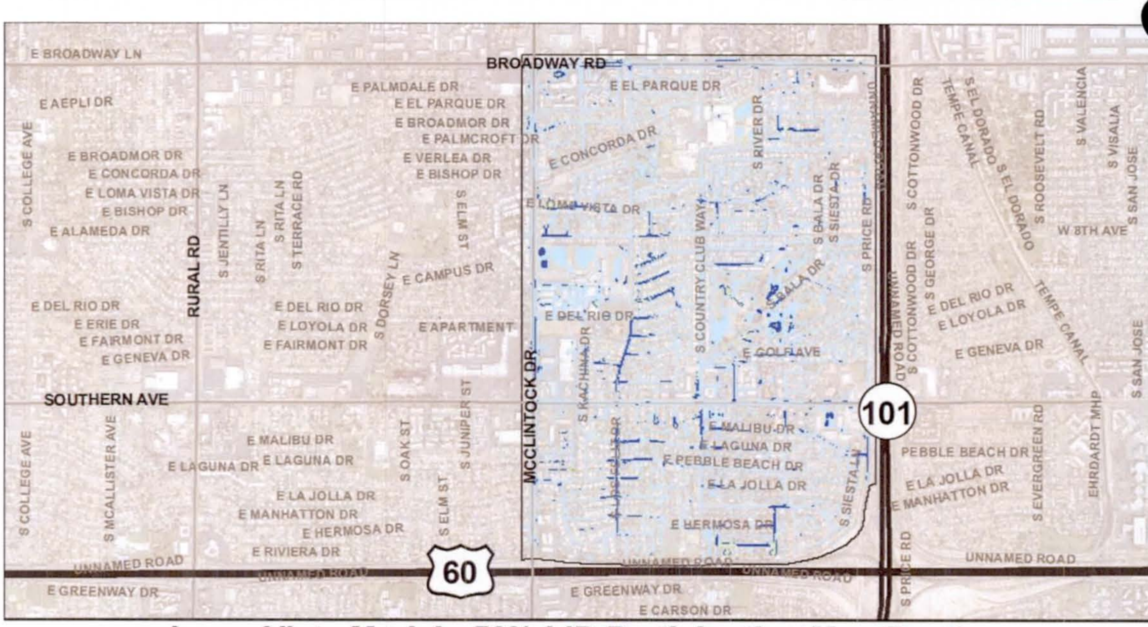
In order to show the impact of LID participation rate on the surface peak flow reduction for the 10-year storm event surface flow hydrographs at two of the floodplain cross sections at the downstream of the modeling area were shown in the following charts with all four (4) LID participation rates. These two charts show that surface runoff reduction increases with the increase of LID participation rate.



McClintock Dr. at Broadway Rd. - 10-Year Storm



Broadway Rd. at McClintock Dr. – 10-Year Storm



Loma Vista Model - 50% LID Participation Max Depths

10 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 3,000 feet

Loma Vista Model - 50% LID Participation Max Depths

10 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

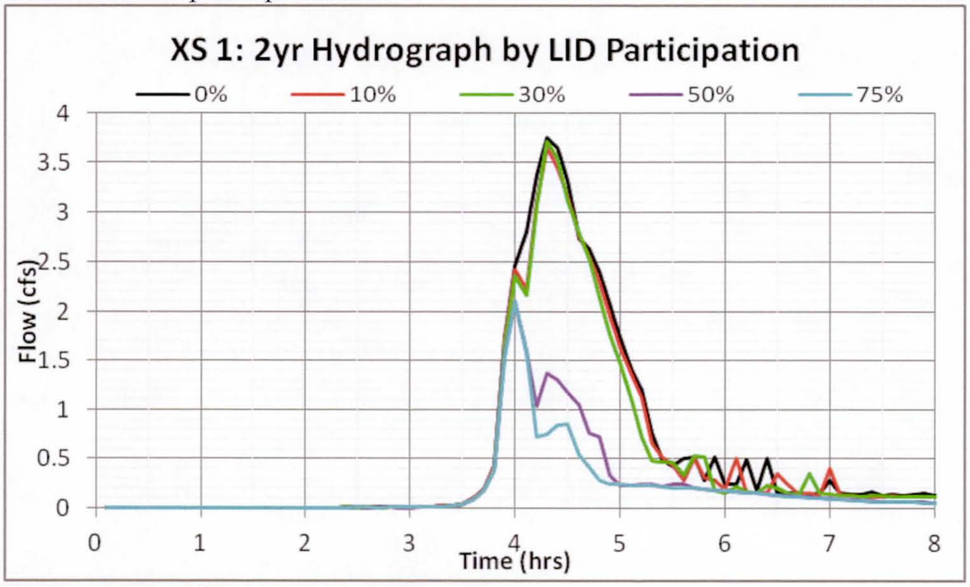
N

1 inch = 400 feet

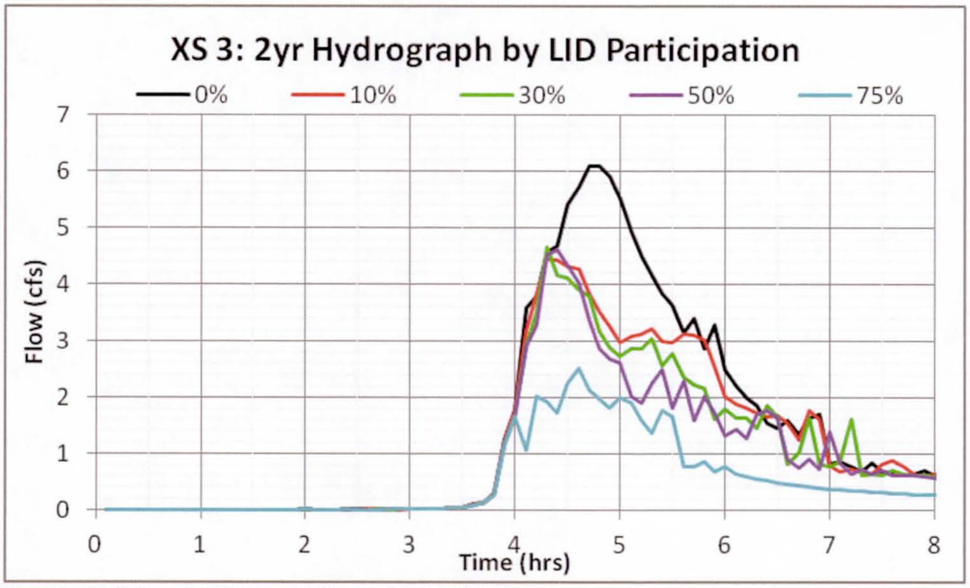
7.4 2-Year Storm Event

The 2-year storm FLO-2D modeling results for the four (5) models were documented in Appendix F and Exhibit E including the base model and the four (4) LID scenarios. The FLO-2D model input and output files and modeling results are included in Appendix F.

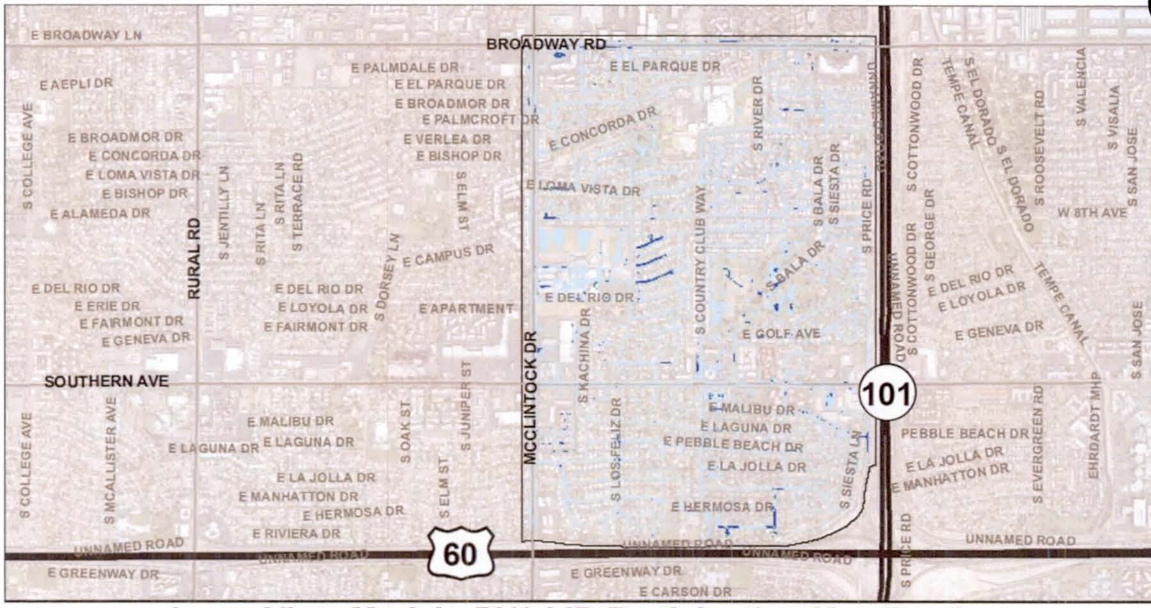
In order to show the impact of LID participation rate on the surface peak flow reduction for the 2-year storm event surface flow hydrographs at two of the floodplain cross sections at the downstream of the modeling area were shown in the following charts with all four (4) LID participation rates. These two charts show that surface runoff reduction increases with the increase of LID participation rate.



McClintock Dr. at Broadway Rd. - 2-Year Storm



Broadway Rd. at McClintock Dr. – 2-Year Storm



Loma Vista Model - 50% LID Participation Max Depths

2 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 3,000 feet

Loma Vista Model - 50% LID Participation Max Depths

2 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 400 feet

7.5 Summary of Multiple Frequency FLO-2D Modeling Results

The FLO-2D modeling results for the multiple frequency storms with the four (4) parcel participation rates were summarized in Tables 7.1 to 7.6:

Table 7.1 documents the modeling results for infiltration and interception variables;
Table 7.2 documents the modeling results for surface floodplain storage variable;
Table 7.3 documents the modeling results for floodplain outflow volume;
Table 7.4 documents the modeling results for stormdrain inflow volume;
Table 7.5 documents the modeling results for stormdrain returning flow;
Table 7.6 documents the modeling results for stormdrain total outfall peak flows.
The values in the tables as functions of the storm size and parcel participation rate were also shown in the charts following each table.

The modeling results show that LID applications are very effective in flood mitigation in reducing the storm runoff volumes.

Table 7.1 Loma Vista Multiple Frequency Results

Infiltration & Interception (ac-ft)		Storm			
		100yr	25yr	10yr	2yr
Participation	0%	36.3	34.3	32.8	28.9
	10%	44.2	42.2	40.2	34.2
	30%	54.7	52.4	49.9	40.8
	50%	70.0	67.3	63.9	50.2
	75%	88.0	84.8	80.0	60.6

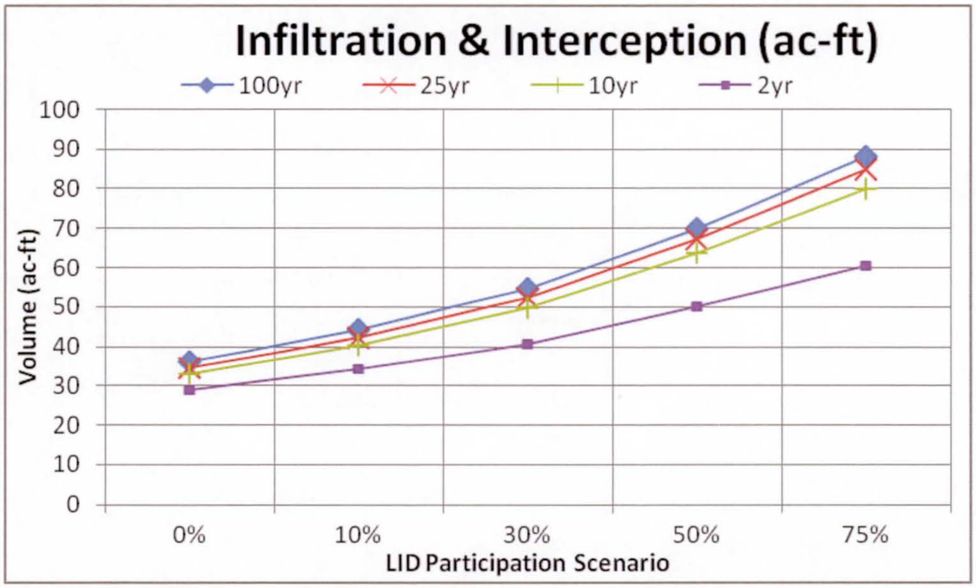


Table 7.2 Loma Vista Multiple Frequency Results					
Floodplain Storage (ac-ft)		Storm			
		100yr	25yr	10yr	2yr
Participation	0%	65.0	51.5	41.0	28.0
	10%	62.7	47.3	38.0	25.9
	30%	59.6	43.6	35.1	23.4
	50%	52.6	36.9	29.6	18.7
	75%	44.6	30.1	22.7	12.8

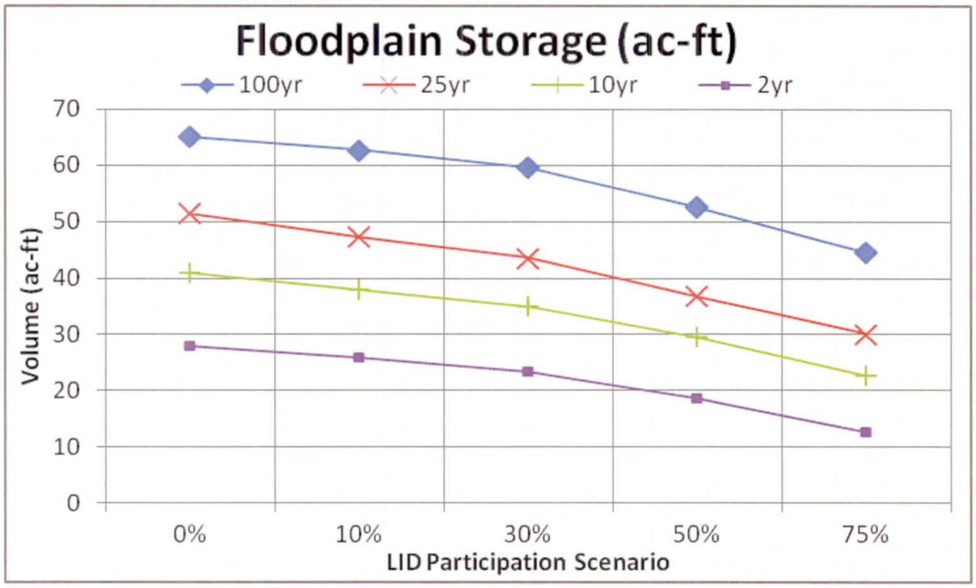


Table 7.3 Loma Vista Multiple Frequency Results					
Floodplain Outflow (ac-ft)		Storm			
		100yr	25yr	10yr	2yr
Participation	0%	36.8	16.3	9.3	3.6
	10%	32.8	14.7	8.4	3.4
	30%	28.0	11.8	7.3	3.1
	50%	19.9	8.7	5.7	2.5
	75%	15.2	6.7	4.5	2.2

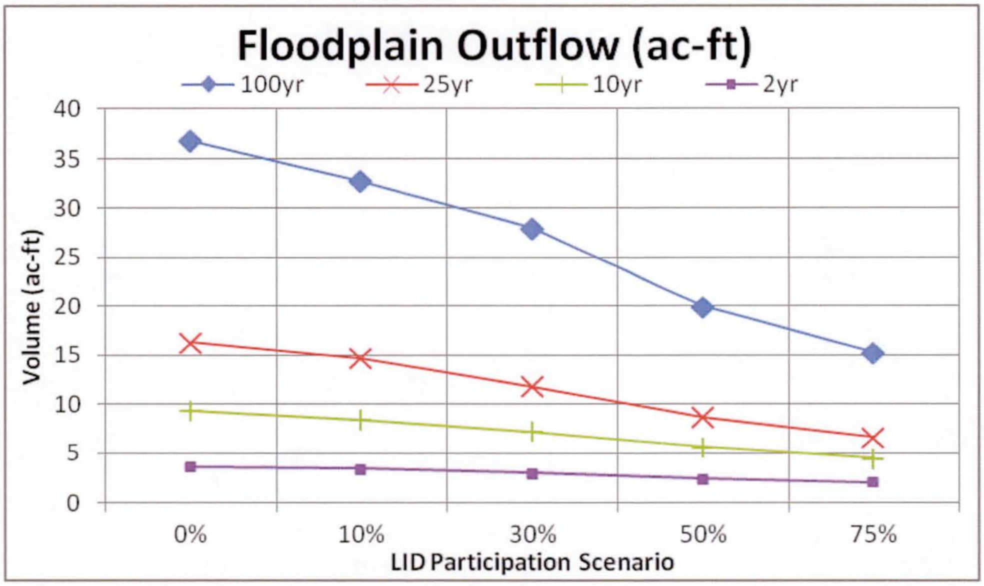


Table 7.4 Loma Vista Multiple Frequency Results

Stormdrain Inflow (ac-ft)			Storm			
			100yr	25yr	10yr	2yr
Participation	0%	SWMM	106.7	95.3	82.4	45.5
		FLO2D	99.8	88.5	75.8	40.3
	10%	SWMM	105.0	91.2	76.8	40.8
		FLO2D	97.9	84.5	70.1	35.9
	30%	SWMM	101.7	86.1	67.6	33.6
		FLO2D	94.5	79.2	61.3	29.8
	50%	SWMM	98.6	76.8	58.4	26.5
		FLO2D	92.5	70.5	51.9	23.4
	75%	SWMM	91.5	65.0	44.2	14.0
		FLO2D	84.7	58.4	38.8	13.6

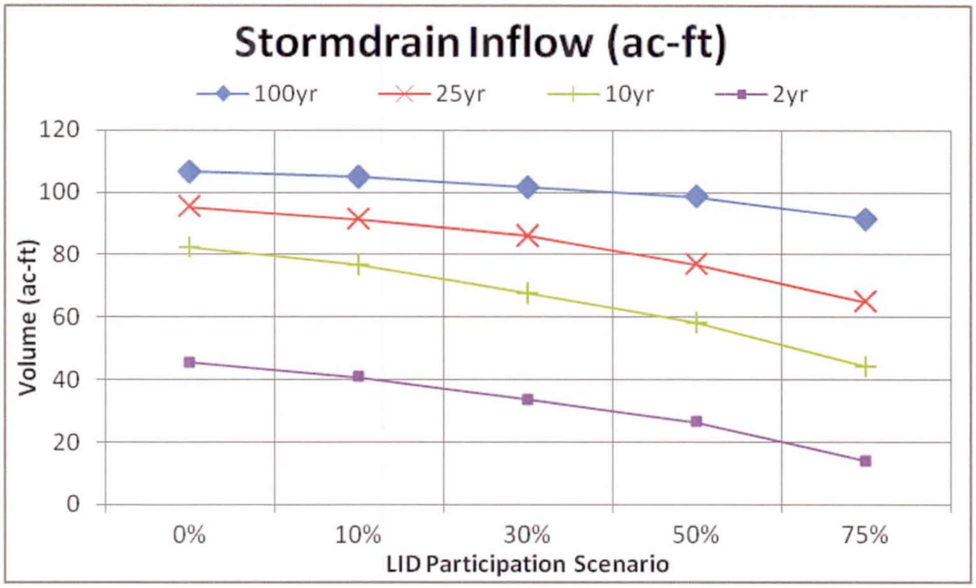


Table 7.5 Loma Vista Multiple Frequency Results						
Stormdrain Return Flow (ac-ft)			Storm			
			100yr	25yr	10yr	2yr
Participation	0%	SWMM	42.8	38.9	33.0	16.3
		FLO2D	33.5	30.0	25.1	12.4
	10%	SWMM	42.1	36.6	30.2	14.6
		FLO2D	33.1	28.0	22.9	11.0
	30%	SWMM	41.2	34.2	26.1	10.8
		FLO2D	32.3	26.3	19.7	8.7
	50%	SWMM	40.0	30.3	22.6	8.2
		FLO2D	30.6	22.8	17.2	6.4
	75%	SWMM	36.8	25.7	16.4	0.5
		FLO2D	28.1	19.5	12.1	0.8

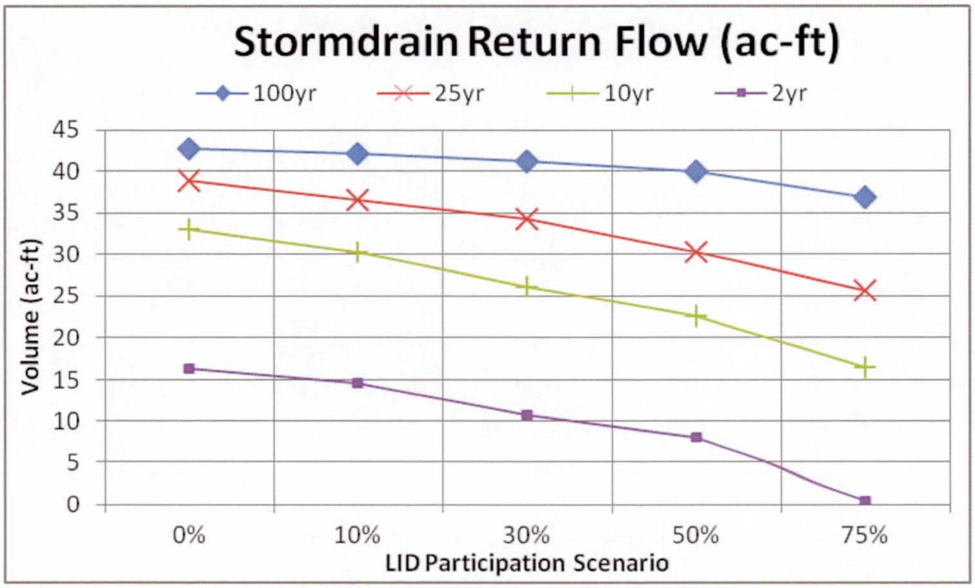
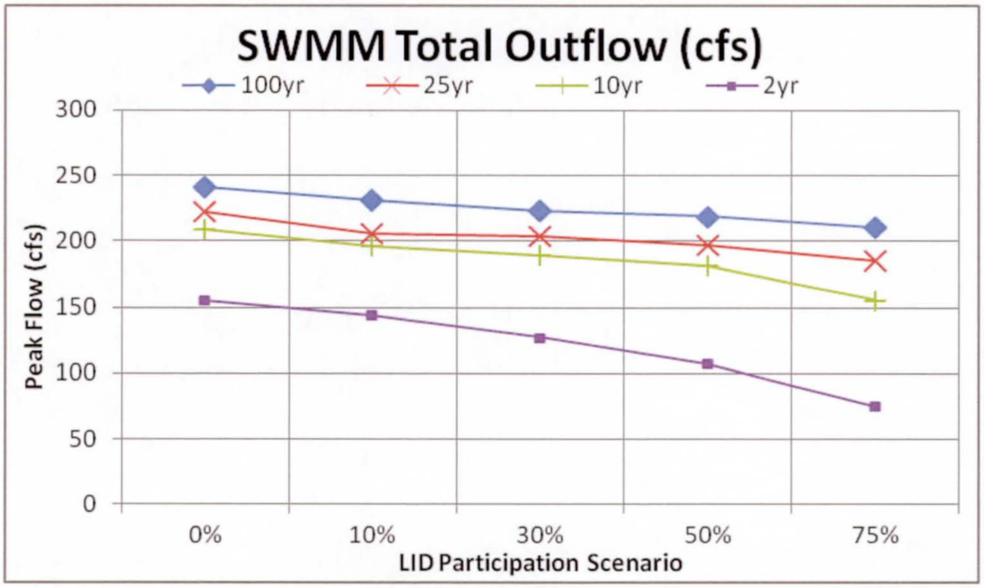
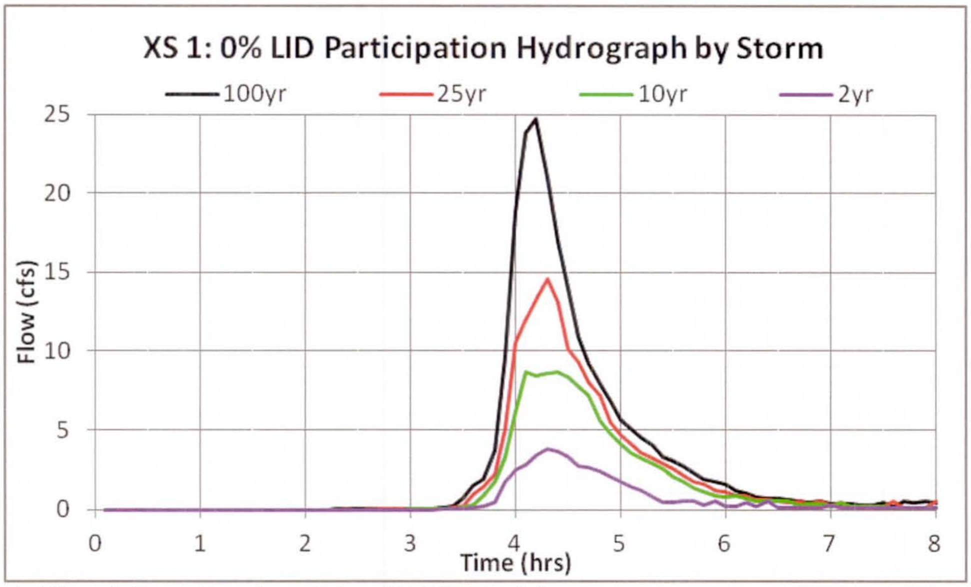


Table 7.6 Loma Vista Multiple Frequency Results					
SWMM Total Outflow (cfs)		Storm			
		100yr	25yr	10yr	2yr
Participation	0%	241.0	222.2	208.9	155.3
	10%	231.3	205.8	196.2	144.6
	30%	223.6	203.9	189.3	127.1
	50%	218.8	196.9	181.4	107.3
	75%	210.4	184.9	155.4	75.3

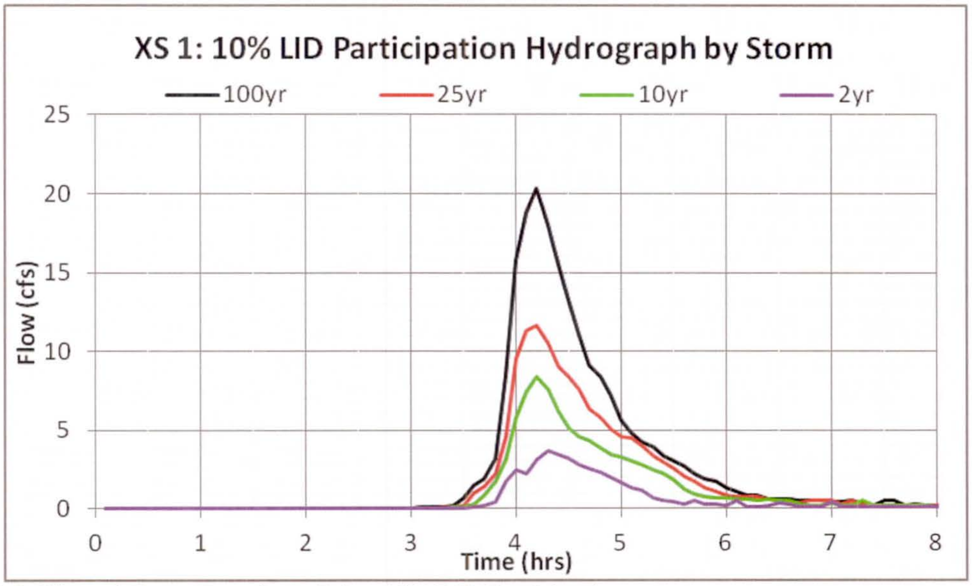


The surface flow hydrographs at two of the floodplain cross sections at the downstream of the modeling area were shown in the following charts in order to show the effectiveness of LID applications on the surface peak flow reduction (all cross section hydrographs are included in Appendix F):

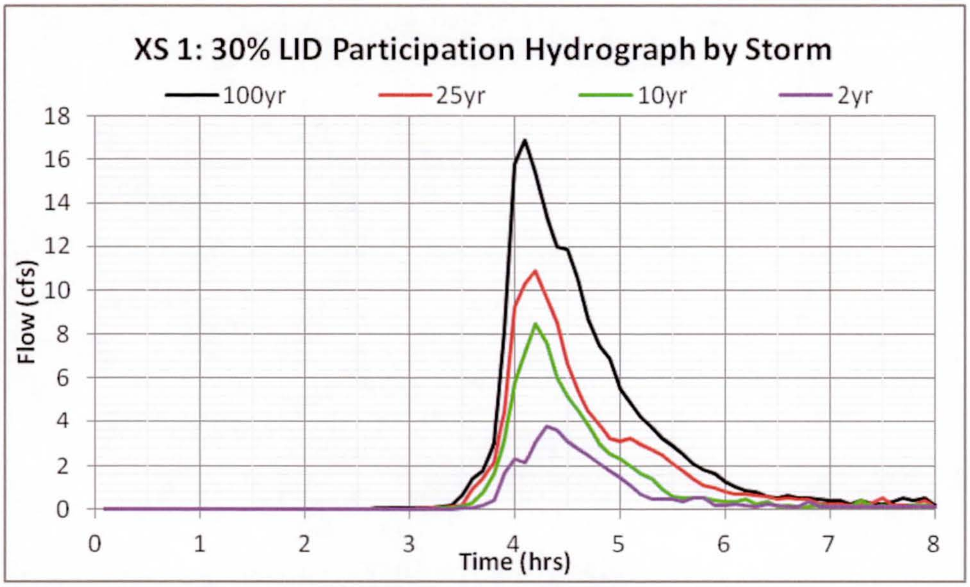
CS #1 is located at McClintock Dr. and Broadway Rd. and the hydrographs charts are listed in the order of LID participation rate. These charts show that the peak flow reduction increases with the increase of parcel participation rate. The peak flow reduces with more frequent storms.



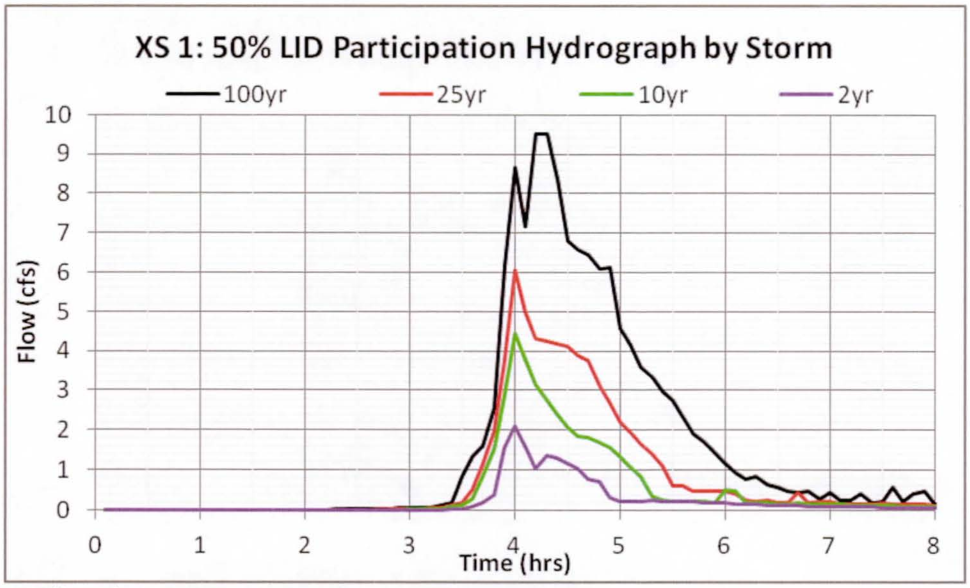
McClintock Dr. at Broadway Rd. – 0% LID Participation



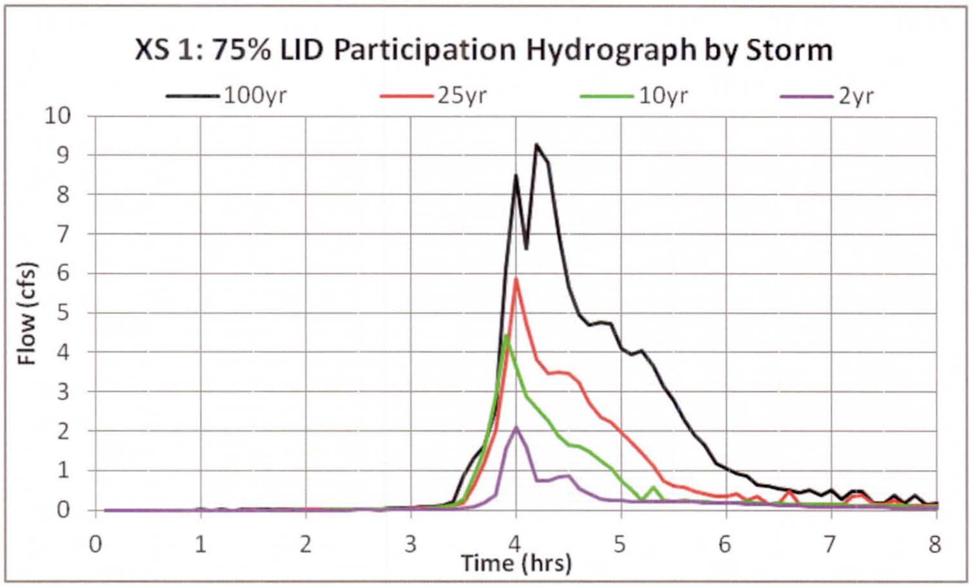
McClintock Dr. at Broadway Rd. – 10% LID Participation



McClintock Dr. at Broadway Rd. – 30% LID Participation

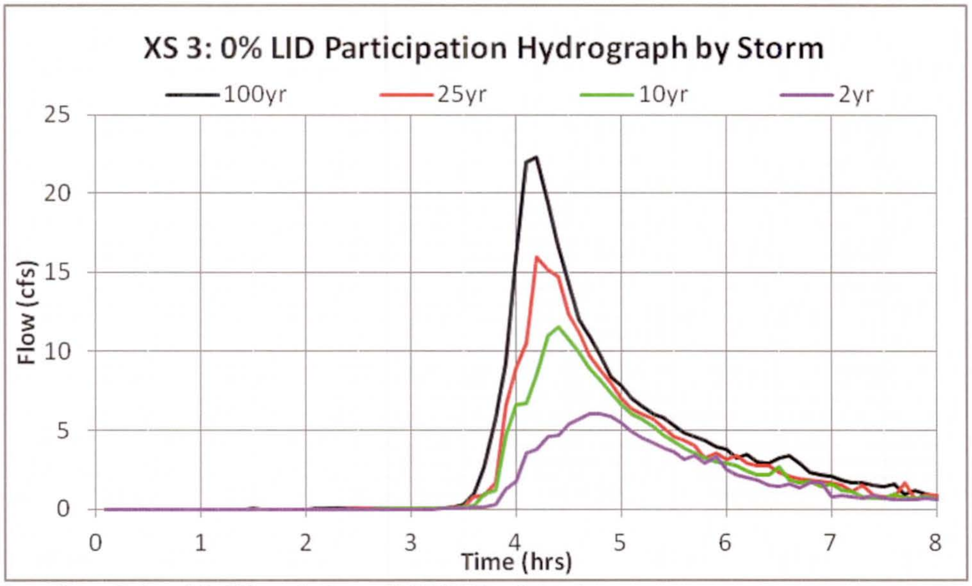


McClintock Dr. at Broadway Rd. – 50% LID Participation

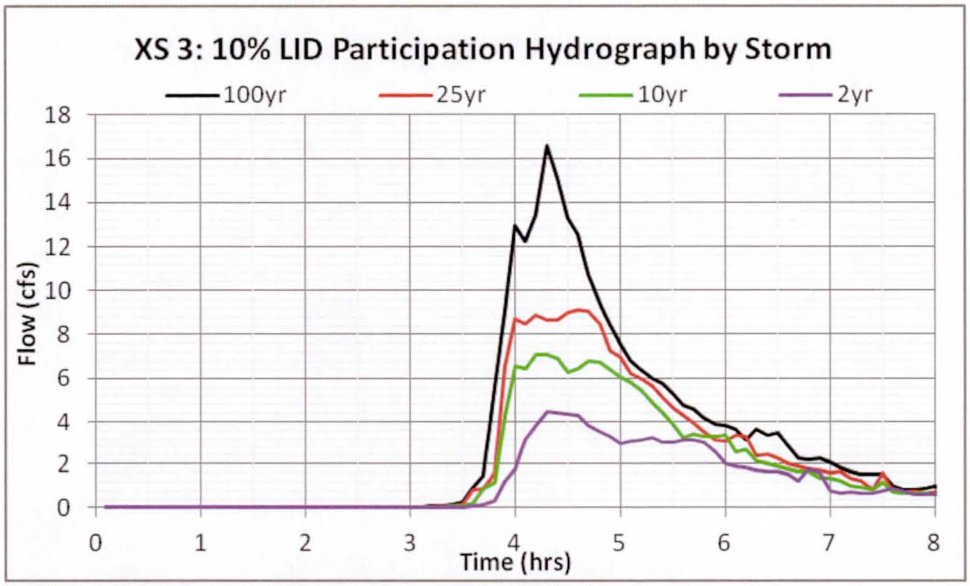


McClintock Dr. at Broadway Rd. – 75% LID Participation

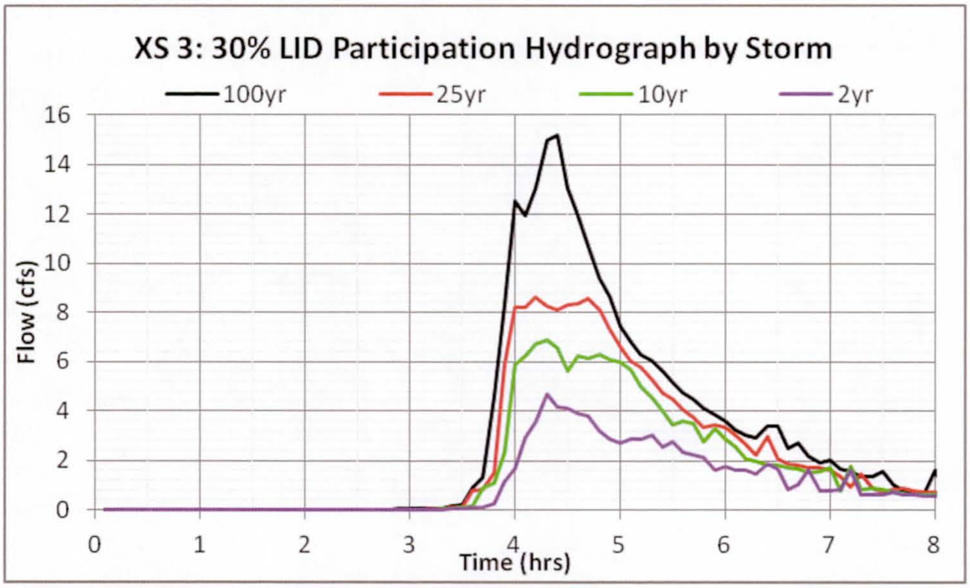
CS #3 is located at Broadway Rd. and McClintock Dr. and the hydrographs charts are listed in the order of LID participation rate. These charts show that the peak flow reduction increases with the increase of parcel participation rate. The peak flow reduces more with more frequent storms.



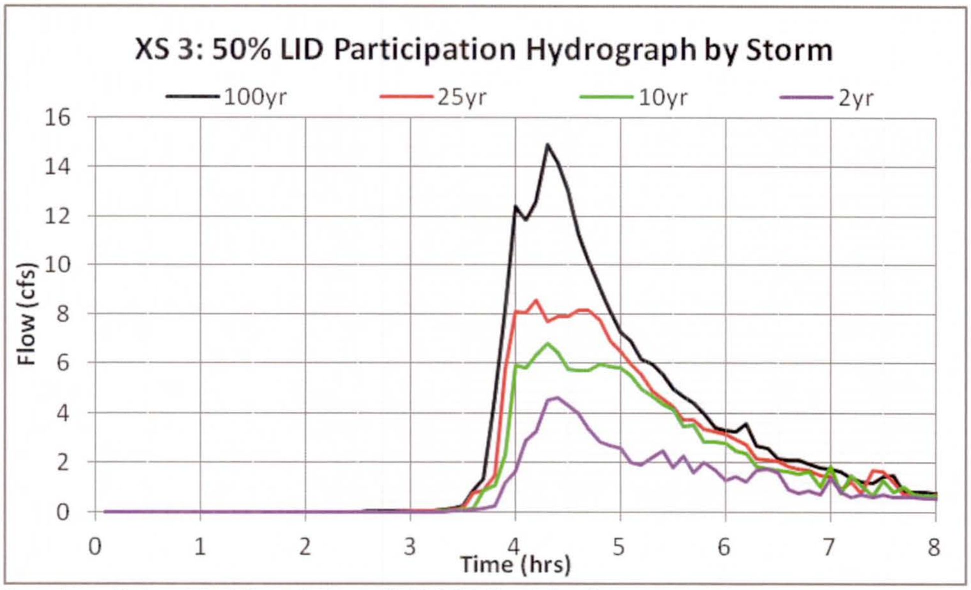
Broadway Rd. at McClintock Dr. – 0% LID Participation



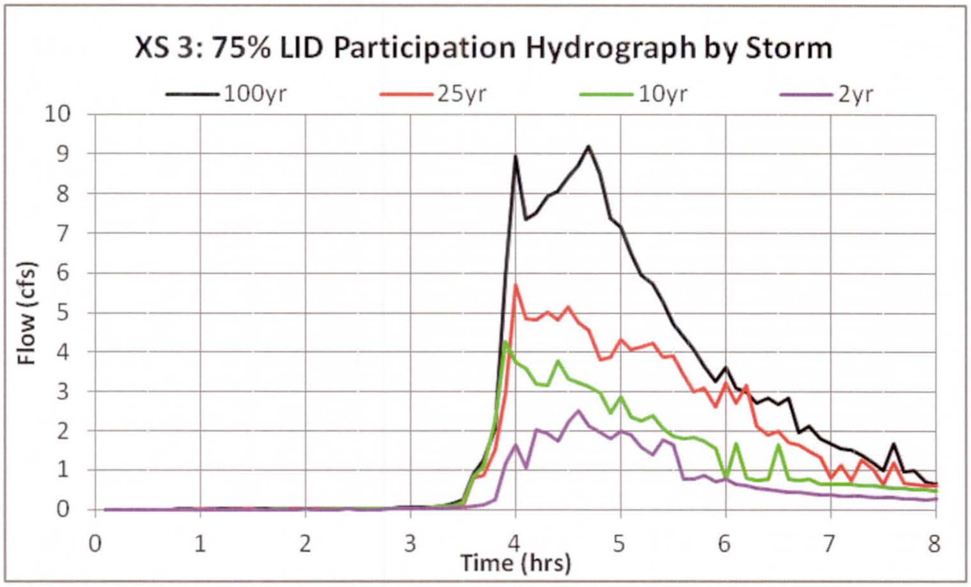
Broadway Rd. at McClintock Dr. – 10% LID Participation



Broadway Rd. at McClintock Dr. – 30% LID Participation



Broadway Rd. at McClintock Dr. – 50% LID Participation



Broadway Rd. at McClintock Dr. – 75% LID Participation

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